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*Finding the Right
Mix of Military
and Civil Airlift,
Issues and Implications*

Volume 1. Executive Summary

*Jean R. Gebman, Lois J. Batchelder,
Katherine M. Poehlmann*

Project AIR FORCE

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FOREWORD

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Shortly after our forces returned from the Gulf War, the Secretary of the Air Force and the Air Force Chief of Staff asked RAND to undertake this research. The work was performed and briefed to the Air Force during fiscal year 1992. The following year, a summary briefing was prepared and presented to the Air Force. Draft documentation was then prepared and reviewed within RAND. During 1994, a revised draft report was reviewed by the Air Force and the aircraft industry.

RAND was asked to perform this work in response to the many changes occurring around the world that may influence the attractiveness of different approaches to the Air Force's investment in its strategic airlift capabilities. Changes have continued to occur through the course of the research and its documentation. They may continue as the Air Force and the Department of Defense continue to grapple with major choices about essential airlift capabilities and the alternatives for providing those capabilities.

The research described in this report can help inform those choices. It explores how the DoD might work toward an affordable strategic airlift capability that has both enough capacity to support major regional contingencies and enough flexibility to go anywhere our nation's interests require the prompt global reach of our combat or humanitarian resources.

Because the DoD's choices in this area involve major investments that will have significant and long-lasting implications for future capabilities, we have aimed to provide the Air Force with an indepen-

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dent research product based upon a broad analysis of matters we judged to be germane to future choices.

As the research and its documentation progressed, there have been many spirited discussions within RAND and the airlift community. These discussions have contributed importantly to the nature and content of the final report. To share the benefit of many of these discussions with the reader, we have included a third volume. It contains 80 topics that are arranged by subject matter in a set of appendixes.

Some of the topics address the research context (Appendix A), others deal with elements of the research (Appendixes B, C, and D) or differences between this and related research efforts (Appendix E). One set of topics (Appendix F) illustrates how this research might be adapted to take into account the continuing changes that are important to future decisions. The final set of topics (Appendix G) identifies important open issues and suggests initiatives for resolving or narrowing these issues. Some key areas to watch are the DoD's continuing assessment of airlift requirements, the DoD's continuing revisions to the CRAF program, the CINCs' perspectives on the need for capacity and flexibility in the airlift fleet, the DoD's Non-developmental Airlift Aircraft program, and the retirement of the C-141 fleet.

PREFACE

Stringent budgets and a changing world prompted the Secretary of the Air Force and the Air Force Chief of Staff to seek an independent estimate of the mix of military and civil airlift that would be sufficient for future needs while minimizing demands on future budgets.

Most of the research for the short-term effort described here was completed during the first six months of fiscal year (FY) 1992, with the remainder of the year devoted to analysis of the Air Force's follow-up questions. The research built upon other RAND work begun in 1990 for the Office of the Undersecretary of Defense for Acquisition;¹ reviews of lessons learned from the Gulf War that were conducted for the Office of the Secretary of Defense, the Army, and the Air Force;² and research requested by the Vice Chief of Staff of the Air Force that addressed the subject of the base force.³ In adding to the airlift analysis methods used in the previously initiated work, this research developed advances in RAND's tools for analyzing life-cycle cost, benefits of aerial refueling, aircraft utilization rates, throughput, and airfield access.

¹Hura, M., J. Matsumura, and R. Robinson, *An Assessment of Alternative Transports for Future Mobility Planning*, Santa Monica, Calif.: RAND, R-4245-ACQ, 1993.

²J. Lund, R. Berg, and C. Replogle, *Strategic Airlift in Operation Desert Shield and Desert Storm: An Assessment of Operational Efficiency*, Santa Monica, Calif.: RAND, R-4269-AF, 1993, and M. Chenoweth, *The Civil Reserve Air Fleet and Operation Desert Shield/Desert Storm: Issues for the Future*, Santa Monica, Calif.: RAND, MR-298-AF, 1993.

³C. Bowie, F. Frostic, K. Lewis, J. Lund, D. Ochmanek, and P. Propper, *The New Calculus: Analyzing Airpower's Changing Role in Joint Theater Campaigns*, Santa Monica, Calif.: RAND, MR-149-AF, 1993.

As research results were produced, they were briefed to the Air Force throughout 1992. At the Air Force's request, a summary briefing was prepared and provided in February 1993. This report presents the details of the research and findings reported in that summary briefing. This report and its two companion volumes⁴ are the final documentation for this research. Since completion of the research in 1992, a number of events related to the research have occurred.

- To expand its authority to activate the Civil Reserve Air Fleet (CRAF) without requiring action by the President (which is needed for Stage III), the Department of Defense (DoD) has increased the size of Stages I and II. For example, Stage I for passenger aircraft is 63 percent larger. Stage II for cargo aircraft is 100 percent larger.
- DoD's continuing revisions to the CRAF program are more broadly linking government business to participation in the CRAF.
- Estimated costs for completing the C-17 program have risen, the schedule has been stretched, and the airplane's payload has been reduced for long distances.⁵
- A congressionally mandated Cost and Operational Effectiveness Assessment for the C-17 was completed by the Institute for Defense Analyses in 1993.
- DoD's continuing assessment of airlift requirements is showing increased needs for airlift during the early weeks of a major regional contingency and even greater needs during the early

⁴J. Gebman, K. Poehlmann, and L. Batchelder, *Finding the Right Mix of Military and Civil Airlift, Issues and Implications: Vol. 2, Analysis*, Santa Monica, Calif.: RAND, MR-406/2-AF, 1994, and J. Gebman, K. Poehlmann, and L. Batchelder, *Finding the Right Mix of Military and Civil Airlift, Issues and Implications: Vol. 3, Appendixes*, Santa Monica, Calif.: RAND, MR-406/3-AF, 1994.

⁵The Institute for Defense Analyses has performed a Cost and Operational Effectiveness Assessment. The General Accounting Office has reviewed the status of the C-17 development program. The Defense Acquisition Board has considered restructuring the acquisition program. The DoD and the C-17's prime contractor have agreed to a restructuring of the acquisition program, including reduced performance requirements for the aircraft. The DoD is considering supplementing its procurement of the C-17 with the purchase of an already developed transport.

weeks of a second, nearly simultaneous major regional contingency.

- The perspectives of the commanders in chief of the unified commands on the need for capacity and flexibility in the airlift fleet are reflected in the outcome of their August 1993 meeting, in which they expressed a very strong desire for a new military-style transport with flexibility like that possessed by the C-17.
- The DoD has launched a Nondevelopmental Airlift Aircraft program to explore alternatives, including military- and civil-style transports that might be procured along with or instead of the C-17.
- DoD has initiated a study of strategic airlift force mixes.
- The entire C-141 fleet is now scheduled for retirement by 2005.

Although the appendixes (Volume 3) address how some of the changes since the completion of the research in 1992 may affect the appropriate use of our work, we have not tried to update the results of the research to account for the continuing stream of changes.

This report is being published at this time to illuminate issues and to illustrate their implications so as to help inform the choices the DoD faces as it searches for the right mix of military and civil airlift.

This project was conducted within the Resource Management and Systems Acquisition Program of RAND's Project AIR FORCE, the Air Force's federally funded research and development center for studies and analysis.

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As our national security strategy is adapting to a changing world, intertheater airlift remains an important instrument for implementing foreign and defense policies, because it provides the Department of Defense (DoD) with the ability to deliver combat forces or humanitarian relief rapidly anywhere in the world and to follow through quickly in response to changing circumstances. Military airlift, however, is the most costly mode of transportation, because it requires specialized military transports that are more expensive than civil transports and have limited utility between crises. Even during the height of the Cold War, the DoD's total supply of military and civil airlift was constrained by budgets and fell short of being sufficient to support the national military strategy for reinforcing NATO. Because our national security strategy continues to place high demands on airlift, and because the supply of airlift will remain fiscally constrained, it is important to invest wisely in the right mix of capabilities.

BACKGROUND

The Military-Style Transport

To replace eventually all of its C-141 transports and some of its C-130s, the Military Airlift Command set forth a master plan in 1983 to procure a fleet of at least 220 C-17 transports that could carry equipment as the C-5 does and land on austere strips as the C-130 does, and maneuver on the ground more like the C-130 does than the way the C-5 does. An aircraft with such a unique set of characteristics could be useful in a variety of military settings. Some of

those characteristics help contribute to the aircraft's performance of intertheater airlift missions; others contribute to its performance of intratheater (tactical) missions. A fleet of such aircraft could directly reinforce NATO's front-line units or rapidly deploy combat units to forward operating locations in other theaters, such as the Middle East.

In addition to its unique ability to deliver outsize cargo to airfields with short runways, the C-17 has unprecedented ground agility for an intratheater transport. It can back up on inclined surfaces, maneuver in close quarters, and park in small areas. It can also perform other functions unique to the military-style transport, including air drop, use of built-in ramps to deliver cargo to airfields with no materiel-handling equipment, low-level operations to evade threats, and rapid offload of cargo on runways under combat conditions. Furthermore, military-style transports have specially designed systems to improve survivability when exposed to combat conditions. Such characteristics give the military-style transport, especially the C-17, the operational flexibility to carry more types of cargo, to more places, under more threatening conditions than can the civil-style transport. The distinguishing feature of military-style transports is flexibility.

The Civil-Style Transport

Although the lack of such flexibility means the civil-style transport has limited utility when applied to military missions, it also means lower costs for the loads that can be carried. Thus, civil-style transports offer the least costly approach for delivering passengers and pallets or containers of cargo to airports with well-established facilities, such as runways that are both long and strong. The civil-style transport becomes especially attractive from a cost standpoint when it can be called upon from the civil sector only when needed to augment military airlift during a very large crisis. The Civil Reserve Air Fleet (CRAF) has provided such a standby capability since the early 1950s.¹ The distinguishing feature of this class of transports and the CRAF is economic efficiency.

¹See Chapter One of Volume 2 for a description of the CRAF program.

Changing Conditions

By 1990, tightening budgets and the relatively large investment planned for the C-17² were making the C-17 the Air Force's largest remaining procurement for the 1990s. However, the world had changed since the concepts for the current military and civil airlift fleets were developed during the 1950s and 1960s and since the concept for the C-17 was defined during the early 1980s.³ Thus, during the spring of 1990, the DoD lowered its procurement objective for the C-17 from 210 to 120 aircraft. To compensate, the Air Force developed a plan to extend the service life for about one-third of the C-141 fleet.

During the summer of 1991, following the return of troops from the Gulf War, the Air Force's leadership recognized that the Air Force's investment plans for airlift may need further adjustment in response to lessons from the Gulf War, changing world conditions, the continuing reduction in force structure, and the prospect of even tighter budgets.

THE QUESTION

To help it address the key airlift policy issues emerging on the horizon, the Air Force asked RAND to prepare an FY 1992 research plan for addressing a large set of questions that can be summarized by the single umbrella question:

What is the most efficient mix of civil and military airlift resources that will provide sufficiently robust capabilities across the range of scenarios and situations for which the Air Force must be prepared?

The Air Force's specific policy interests included such questions as whether it could improve its allocation of resources with such policy choices as the following:

²At the beginning of FY 1992, the acquisition plan called for a total investment of \$35 billion (then-year dollars) for research, development, and production of 120 aircraft. Through FY 1992, the DoD had been authorized to use \$11 billion of this amount.

³Chapter One of Volume 2 describes the airlift fleets, their transports, and their cargo: bulk (fits on pallets), oversize (fits in C-130s and C-141s), and outsize (fits only in C-5s and C-17s).

- Stop the C-130 production line now and rely later upon the C-17 to provide any necessary replacements for retiring C-130 transports.
- Rely more on civil airlift and buy fewer C-17s.

The Air Force sought an independent estimate of the *right mix* of military and civil airlift, because the cost of maintaining the nation's emergency airlift capabilities is very sensitive to choices about the mix of civil and military airlift and to choices about the quantities and types of transports owned and operated by the government.

THE RESEARCH

To address these policy questions, the research focused on six subjects: (1) capacity of the 1992 airlift fleet, (2) changes in demands for airlift, (3) improving the application of civil airlift, (4) improving the application of military airlift, (5) closure of the C-130 production line, and (6) analysis of alternative fleet mixes.

1. Assessment of the Throughput Capacity for the 1992 Airlift Fleet

Approach. We found that an estimate for the daily delivery capacity of an airlift fleet is very sensitive to the values used for key parameters: aircraft payloads, utilization rates, block speeds, the mix of loads to be delivered, and the level of CRAF participation. Instead of using traditional planning factors, we developed special methods to make independent estimates for these key parameters. Where possible we used the Gulf War experience to either calibrate or test these methods and estimates. Our estimates differ enough from the Air Force's planning factors and values used in other airlift analyses to cause significant differences in estimated fleet capabilities, estimated fleet sizes, and therefore, estimated fleet costs when comparing alternative fleets.⁴ Our research methods are described in Volumes 2 and 3.

⁴See Chapter Six and, in Volume 3, see Appendix E.

Findings. Both our research methods and data from the Gulf War airlift showed that the amount of airlift capability that could actually be applied to the first 30 days of a major regional contingency, such as the Gulf War, is less than half that suggested by planning factors for payloads, utilization rates, block speeds, the mix of loads being delivered, and the level of CRAF participation. Because the realistically available level of airlift capacity is less than what has been deemed to be needed, it is even more important to make the best possible investment in new airlift resources to provide both the capacity and flexibility that major contingencies require.

2. Shifting Demands for Airlift

Approach. To understand how the demands for airlift are changing, we analyzed the experience of the Gulf War airlift and examined the DoD's assessment of the airlift requirement as it was reflected in the 1992 Mobility Requirements Study.

Findings. Demands for airlift have shifted; whereas delivering reinforcements with large amounts of outsize equipment to NATO's well-prepared airfields was once a chief concern of airlift analyses, analyses are now faced with the question of how to best deliver a mix of mostly oversize and bulk cargo that is needed to deploy and sustain forces in theaters lacking the preparation and indigenous resources that exist in Western Europe. At the time of publication in late 1994, the DoD's most recent assessments of airlift requirements call for 85 percent of the materiel delivered by air during the first 30 days to be oversize and bulk.

3. Improve the Application of Civil Airlift

Approach. Because civil airlift is much less costly than military airlift, and because it can carry both oversize and bulk cargo, we explored the possibility of an even larger and more effective role for the CRAF. To do this, we examined the costs and benefits of the 1992 CRAF arrangements for both the government and the air carriers. We also analyzed the CRAF's participation in the Gulf War airlift and explored how changes in force structure would influence future incentives for CRAF participation. Finally, we examined concepts for

either improving incentives or adopting other means for achieving an even larger role for CRAF in the future.

Findings. We found that CRAF has been a very cost-effective program for the government and an important business opportunity for small air carriers who were very interested in obtaining as much government business as they could at all times, including during emergencies, such as the Gulf War airlift. At the time of the Gulf War, CRAF Stage I included many aircraft from small air carriers. In contrast, CRAF Stages II and III were dominated by aircraft from the large air carriers, who welcomed the government's routine business but were reluctant to satisfy surges in demands that would occur in response to an activation of Stage II or III. To those carriers, activation would jeopardize their investments in those markets where they would have to remove aircraft to satisfy the government's needs. Thus, the amount of civil airlift that can be relied upon for emergencies is uncertain, because activation of CRAF Stages II and III progressively introduces large disruptions in the operations of large air carriers in ways that might produce significant economic consequences for the air carriers.

We assumed CRAF availability at a level equal to the Stage II capability that was eventually activated for the Gulf War airlift. We think, for fleet planning purposes, that going far beyond that level entails risks that the disruption to the private sector may be judged to be too great to warrant activation for many situations that the DoD will face over the next several decades. Several concerns underlie such reasoning. For the Gulf War airlift, Stage II capability was actually needed earlier, but activation was deferred until after the Christmas holidays. Moreover, when Stage II was activated, the backlog of materiel needing shipment actually warranted more than a Stage II activation, but there was reluctance to go beyond that stage.

We considered a broad range of possibilities for at least preserving—and possibly increasing—the role of the CRAF. Although no concept seemed free of what we saw as potentially serious drawbacks, others may judge the possibilities differently. For example, making CRAF participation a precondition for doing any business with the government is one such possibility currently being implemented by the government. Another possibility that we considered is giving the air carriers a subsidy for participation in the CRAF. Although further

exploration of such possibilities—and others—is warranted, we did not find a compelling case to support the belief that the CRAF could be expanded to compensate for a reduction in the military airlift fleet, such as the retirement of two-thirds of the C-141 fleet. Moreover, for fleet planning purposes, it seemed most prudent to rely on no more than the CRAF Stage II capabilities used to support the Gulf War airlift.

To the extent that the government's recent changes to the CRAF prove successful, then, there may be less need for the government to own and operate civil-style transports. Success, however, includes having the CRAF capability available at the start of a mobilization. The issue is whether the private sector can deliver a large portion of its cargo airlift capacity without triggering unacceptable consequences.⁵

4. Improve the Application of Military Airlift

Approach. Because an efficient mix of military and civil airlift is one that makes best use of available resources, we explored the possibility of more effectively applying both military airlift resources and CRAF resources. We analyzed the operations of the military-style transports during the Gulf War airlift and used our airlift models to identify the factors that caused actual utilization rates to fall significantly short of the Air Force planning factor values. To deal with these factors, we explored such possibilities as increasing the number of aerial ports and the use of aerial refueling to reduce the number of ground stops.

Findings. The daily delivery capacity of the airlift fleet can be increased by improving processes for command, control, communication, and computers (C⁴) to facilitate

⁵For example, as industry has adopted lean production methods, companies have grown to rely on fast transportation instead of large inventories to make production more responsive and less costly. Thus, a Stage II or Stage III activation of private sector transports may trigger consequences that could not only slow the economy but also hurt the economy's ability to rapidly produce what may be needed to support a major crisis.

- how the Air Force matches transports to the loads being deployed, uses tankers to augment the range of transports, and uses transport aircraft air crews—especially those qualified for aerial refueling
- how the airlift users package materiel to use the available volume of each transport
- how the theater commanders schedule the deployment of units to avert bottlenecks at APOEs.

Daily delivery capacity can also be increased by reducing ways that transports spend time on the ground. Chief opportunities are

- reducing time that transports spend being loaded at APOEs by managing the flow of aircraft to match the ability of APOEs to efficiently load aircraft
- ensuring that aircraft do not have to wait for space to become available at an APOE by loading transports at many APOEs simultaneously
- reducing the number of ground stops for military transports by using aerial refueling to increase sortie lengths and by positioning air crews to avoid stops just to change crews; this also reduces wear on systems with high maintenance needs, which in turn reduces failures and cuts the time that transports must spend receiving unscheduled maintenance.

5. C-130 Production Line

Approach. Because we found that the main question was whether the C-17 could provide access comparable to that of a C-130, the research focused on the comparative capabilities of these aircraft to use makeshift landing strips and austere airfields within a theater.

Findings. Based on the information available at the time of the research (1992), we found the C-130 probably has much greater access than the C-17 to austere airfields with weak runways and makeshift landing areas, such as dirt strips and roadways, because the C-130 is less stressful on landing areas and because its type of engine tends to be less prone to ingesting damaging material than the C-17's type of

engine. Thus, we found that the Air Force could not shut down the C-130 production line based upon the expectation that the C-17 could replace all of the capabilities of the C-130. Forthcoming tests of the C-17 should show how significant a difference exists between these aircraft.

6. Alternatives for Replacing Two-Thirds of the C-141 Fleet

Approach. We assumed that the airlift capacity of the retiring C-141s needed to be replaced. We considered a large variety of different combinations of aircraft as alternatives to the Air Force's 1992 plan to procure 120 C-17s. To evaluate the alternatives, a scenario was assumed, and the number of aircraft in each fleet was set to provide comparable daily deliveries for the scenario. Benefits and costs for each alternative fleet were assessed using several different ways to measure daily deliveries and costs. In addition to fiscal costs, infrastructure costs were evaluated in terms of such matters as ramp space used and fuel consumed.

Our goal in designing the scenario was to be mindful of the lessons from the Gulf War while also making the scenario tough enough to ensure that each of the alternative fleets could handle a broad range of scenarios and situations for which the Air Force must be prepared.

For the base case, we took the Air Force's 1992 plans for the C-5 and the C-141 fleets. This meant continuing the service of 126 outsize-capable C-5s and 94 oversize-capable C-141s (following extensive modifications to prolong service life).

For the alternative fleets that would be added to the base case, we examined the comparative capabilities of the transports to use theater airfields.

Findings. At the heart of the inventory question facing the Air Force in 1992 was a difficult tradeoff between the flexibility and relatively greater outsize cargo capacity of a military airlift fleet that includes 120 C-17s and the lower cost of a military airlift fleet that includes a large civil-style transport.

Using our estimates for key parameters—especially average payloads, utilization rates, and block speeds—we found that the Air Force could conserve resources and still meet our assessment of fu-

ture intertheater airlift needs by buying fewer C-17s than planned and buying a civil-style transport with long-range capability to carry bulk cargo and oversize equipment.⁶ In doing so, however, the Air Force would sacrifice the operational flexibility of the C-17, including the abilities to conduct airdrop operations and to carry outsize cargo.

Another part of that flexibility is manifested in the C-17's ability to access both primary and secondary airfields. We analyzed airfields outside of the United States, China, and the former Soviet Union and its allies. We found the 747-400F would be able to use only about 650 airfields, whereas the C-17 could use about 1,800 for major APOD operations. (The Air Force, using different methods, has found an even wider difference.) We also found, however, that the C-17 and the C-5 could use just about as many airfields for major APOD operations. Although the C-17 can use shorter runways, the C-5 can use weaker runways, because its landing gear more broadly distributes loads and thereby causes lower stresses in runway pavements.

In formulating our 1992 best estimate for the right mix, we made the following assumptions:

- The pattern of bulk cargo deliveries would match the experience of the Gulf War airlift. Oversize and outsize cargo, however, would be a representative mix for the U.S. Army's five rapid deployment divisions.
- The CRAF Stage II resources used in the Gulf War airlift⁷ represent a reasonable level of CRAF participation that can be relied upon—for fleet planning purposes—over the next several decades. For serious crises, we assumed that those resources would be available at the start of a deployment.
- It was sufficient to retain one-third of the C-141 fleet to perform the brigade airdrop and other special military missions now

⁶Half of our estimated load mix drew heavily upon the Gulf War's experience, in which palletized materiel (categorized as "bulk" by the DoD) accounted for 48 percent of the load delivered by airlift during the critical first 30 days. Whereas we assumed that half of the load would be bulk for the first 30 days, current DoD plans call for only 25 percent. The remainder would be such equipment as rolling stock and helicopters.

⁷The 1994 CRAF Stage I provides 8 percent more capacity than the CRAF Stage II did during the Gulf War airlift.

performed by the C-141, such as rapid unloading on runways in threatening environments.

- Some loss of flexibility could be tolerated to reduce the loss in total airlift capacity that might otherwise be forced by budget constraints.
- Budget constraints were predominant considerations in selecting the mix.

Given these assumptions, our best estimate of the right mix was one that has civil-style transports to provide needed replacements for the *two-thirds* of the C-141 fleet then designated for retirement. Substitution of a modified 747-400F for the C-17 to replace two-thirds of the C-141 fleet would lower costs considerably. For example, based upon our estimates for key parameters, we found the 25-year cost (1993 through 2017) for a fleet of 747-400Fs would be \$25 billion (1992 dollars) lower than the alternative fleet of 120 C-17s. Other estimates for these same key parameters⁸ suggest a more modest opportunity for lowering costs of about \$7 billion (1992 dollars). This may underscore the sensitivity of cost and capability comparisons to a relatively small number of parameters, which are themselves worthy of more concentrated attention.

ORGANIZATION OF THE REPORT

We have presented this research in three volumes. Volume 1 is an executive summary that encompasses the main points of the other volumes. Volume 2 presents the more detailed analysis underlying our findings.⁹ Volume 3 addresses topics that have been the subjects of interesting discussions during the latter phases of the research and its documentation.¹⁰

⁸See Appendix E of Volume 3 and Chapter Four of Volume 2.

⁹J. Gebman, K. Poehlmann, and L. Batchelder, *Finding the Right Mix of Military and Civil Airlift, Issues and Implications: Vol. 2, Analysis*, Santa Monica, Calif.: RAND, MR-406/2-AF, 1994.

¹⁰J. Gebman, K. Poehlmann, and L. Batchelder, *Finding the Right Mix of Military and Civil Airlift, Issues and Implications: Vol. 3, Appendixes*, Santa Monica, Calif.: RAND, MR-406/3-AF, 1994.

Chapters Two through Six of this volume summarize the analysis in Volume 2. Chapter Two addresses factors that had a significant influence on our estimate of the right mix. The next two chapters explore ways for obtaining more airlift from the civil sector (Chapter Three) and from existing military airlift assets (Chapter Four). Because analysis of the Gulf War airlift demonstrated that the existing fleet can provide more capacity, Chapter Four explores that potential. The research has focused on intertheater airlift, with the one exception of the C-130 production line issue. Chapter Five addresses that issue by analyzing the comparative airfield access capabilities of the C-130 and the C-17. Chapter Six examines alternative mixes of C-17s and civil-style transports for the military airlift fleet. Chapter Seven presents conclusions.

FACTORS THAT INFLUENCE THE ESTIMATE FOR THE RIGHT MIX

Several factors influenced our 1992 estimate for the right mix: (1) Analysis of the Gulf War showed that airlift capability had been overestimated, principally because CRAF expectations had not been fully realized and planning factors for airlift operations had been overly optimistic; (2) changes in the C-17's design had affected its ability to perform C-130 missions; (3) shifting demands for airlift had reduced the need for outsize airlift capability, raising doubts about the 1992 plans for how to replace the C-141; and (4) aging C-141 aircraft were forcing an early decision about the right mix.

AIRLIFT CAPABILITY HAS BEEN OVERESTIMATED

Yielding to budget pressures during the early 1980s, the DoD settled on a compromise objective of 66 million ton-miles per day for cargo as an objective for building an airlift capability necessary to support the national security strategy for reinforcing NATO.¹ By 1991, the airlift enhancement programs of the 1980s resulted in a total capability of 49 million ton-miles per day according to the Air Force's approach to assessing overall airlift capability (Figure 1). However, during the peak month of airlift activity in support of the Gulf War, the largest airlift of all time, the United States' airlift produced only

¹If achieved, such a capability would mean that 20,000 tons could be delivered daily over a distance of 3,300 n mi. The distance from Dover AFB to Torrejon, Spain, is 3,300 n mi; the distance from Charleston AFB to Torrejon is 3,700 n mi.

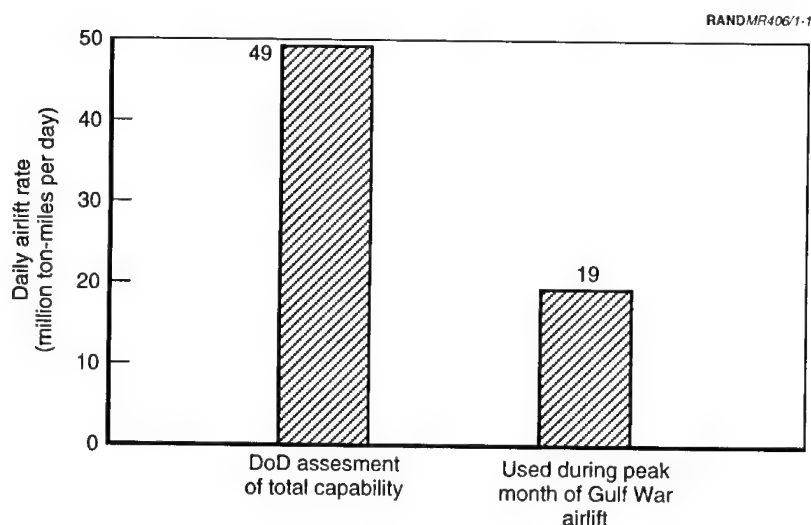


Figure 1—DoD's Assessment of Total Airlift Capability in 1991 and the Average Daily Capability Used During the Peak Month of the Gulf War Airlift

19 million ton-miles per day.² The DoD's assessment of airlift capability was 2.5 times larger than the capability actually used for the peak month, primarily because (1) CRAF carriers successfully resisted a full activation of the CRAF's cargo transports; (2) there were inefficiencies in the scheduling of airlift; and (3) even with an assumption of perfect scheduling, planning factors used to assess military airlift capabilities were too optimistic.³ Chapter Four addresses ways to get more airlift from existing resources through actions that could help improve the efficiency of scheduling.

Resistance of CRAF carriers emerged during the Gulf War airlift's second surge (December–January) as a backlog of bulk cargo accu-

²An average of 3,600 tons were delivered daily. The average distance was 5,300 n mi during that month. If airlift could have provided 49 million ton-miles per day, deliveries would have amounted to 9,000 tons daily.

³Although some airlift resources were used to support the DoD's other commitments, such applications account for no more than 15 percent of the difference.

mulated at Dover AFB. To help handle the surge, the Military Airlift Command (now the Air Mobility Command [AMC]) started to explore the possibility of seeking the necessary action by the president to activate the third and final stage of the long-range cargo element of the CRAF, which would have increased CRAF's cargo airlift from 5 to 17 million ton-miles per day. Meanwhile major air carriers informed the White House that full activation would cause significant disruption to commerce and would adversely affect the long-term competitiveness of those carriers that had made large commitments to the CRAF. In light of these facts, we assumed that CRAF Stage III would not be available in all but the most dire of national emergencies.

Optimistic planning factors have also caused airlift capability to be overestimated. By modeling airlift missions for a deployment of forces from bases in the United States to bases in Saudi Arabia, we found that the Air Force's planning factors greatly overestimate not only aircraft utilization rates (for the C-5 and C-17) but also average payloads (for the C-5, C-141, and C-17) and average block speed (for the C-17).⁴ The actual performances of the C-5 and the C-141 during the Gulf War airlift confirm that the Air Force's planning factors for these aircraft have been too optimistic for utilization rates and average payloads.⁵ The greatest discrepancies occur with the utilization rates for the C-5 and the C-17. For the C-5, the Air Force's planning factor for daily utilization during a 30-day surge is 11 flying hours per day, whereas our estimate is 7.4 hours per day under conditions of perfect scheduling. The actual worldwide experience was 5.5 hours per day during the peak month of the Gulf War airlift. For the C-17, the Air Force's utilization goal of 15.65 hours per day contrasts with our estimate of 12.2 hours per day under ideal scheduling conditions.⁶

To represent the actual airlift capabilities of different mixes of aircraft, we modeled the airlift mission process rather than use the Air

⁴See Figure 4.34 in Chapter Four of Volume 2.

⁵See Figures 4.5 and 4.6 in Chapter Four of Volume 2.

⁶Since the completion of this research, the Air Force has lowered the wartime utilization rates for the C-5 and the C-17 to 10.87 and 15.15 hours per day, respectively. It has also set the planning factor payload for the C-17 at 90,000 lbs.

Force's planning factors for aircraft utilization rates. To do this, we considered actual air bases and mission routes for specific units being deployed. We used performance and maintenance characteristics for the different aircraft and considered the characteristics of the loads to be delivered. By applying our modeling process to a Southwest Asia deployment, we found that, although the DoD had used overly optimistic planning factors, it also had significant opportunities to realize more airlift capability from its existing resources than it was able to use in support of the Gulf War airlift. For example, the C-5's utilization rates could be increased from 5.5 to nearly 7.4 hours per day with improved scheduling. Such opportunities are explored in Chapter Four to ensure that the estimate for the right mix assumes the best use of both existing and new resources.

THE C-17's DESIGN CHANGES

Although the C-17 was conceived initially as a transport that would include the austere airfield capabilities of the C-130, design changes during the mid-1980s had the effect of reducing the C-17's ability to use austere airfields. The changes to the landing gear design reduced the weight of the landing gear at the expense of imposing higher stresses on runways.

The 1982 Request for Proposal for the C-17 called for an aircraft with a load classification number (LCN) of 40 when landing with 120,000 lbs of payload and sufficient fuel for flying 500 n mi after delivery of the payload.⁷ Following selection of the prime contractor, the specifications for the aircraft were developed, and the development contract was signed in 1985. In developing the specifications, the Air Force accepted an LCN of 48 to allow for lighter-weight landing gear. The weight saved in the landing gear meant that the aircraft would have a better opportunity to achieve other important performance objectives. At the time, the trade may have seemed reasonable in view of the many strong concrete runways in Germany that could be used by the C-17 in delivering tanks to reinforce NATO's front-line units. The trade, however, reduced the ability of the C-17 to perform

⁷The LCN is used as an indicator of the peak level of stress that particular aircraft would apply to a particular runway. The higher the LCN, the greater the stress and strain that a runway will experience. See Chapter Five of Volume 2.

C-130 missions in other parts of the world, where concrete runways are not as available. Thus, the degree to which the Air Force could generally rely upon the C-17 to replace the capabilities of the C-130 depends upon the extent to which the C-17's revised design allows it to use airfields accessible to the C-130. Chapter Five explores this issue.

SHIFTING DEMANDS FOR AIRLIFT

The enormous needs imposed by the Cold War strategy that called for quick reinforcement of NATO's established theater led to a heavy emphasis on transports that could quickly move combat equipment, such as the C-5. Some of that equipment, called *outsize*, could only be moved by the C-5. The Army, which has most of the military's outsize materiel, requires a very high number of C-5 missions to airlift its mechanized and armored divisions (Table 1). Because meeting the needs of this strategy with only military airlift would have been too costly, a large CRAF was established. Other means, such as prepositioning and sealift, also became important parts of the mobility strategy.

The Gulf War presented a more distant region, increasing deployment distances by over 50 percent and requiring the Army's mechanized and armored divisions to be delivered by sealift. It also pre-

Table 1

Number of C-5 Missions Required to Carry the Outsize Equipment for Various Units of the U.S. Army

Type of Unit	C-5 Missions Required
Divisions, when moved exclusively by airlift	
Airborne	21
Air Assault	82
Infantry	18
Mechanized	757
Armored	787
Patriot battery, when moved exclusively by airlift	
With 2 launchers	8
With 8 launchers	13

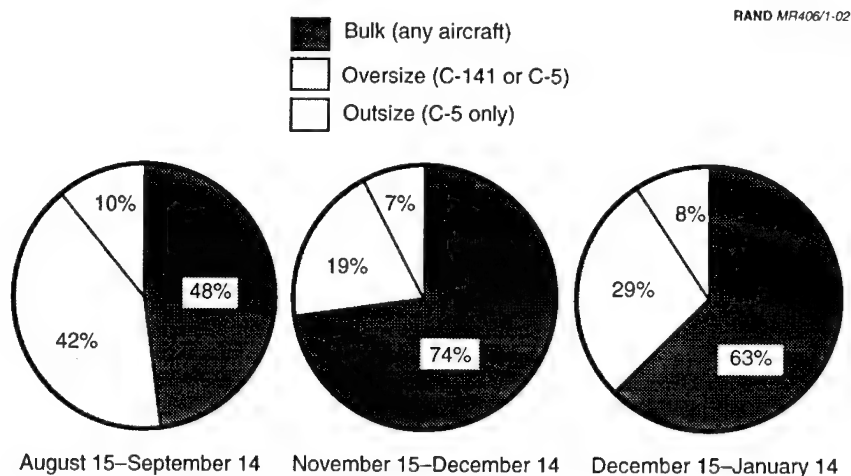


Figure 2—Estimated Mix of Gulf War Cargo Loads

sented a relatively barren theater with different needs. If future demands are similar, a broad mix of loads will need airlift services. The Air Force estimates that, initially, one-half of the cargo shipped by air during the war was bulk cargo. That proportion later expanded to three-fourths (Figure 2). Bulk cargo can be carried in the baggage compartments of civil transports, as well as on the main decks of civil transports that have been configured in a freighter mode, and of course bulk can be carried on the military transports (C-141 and C-5). Civil transports played a significant role in airlifting one-fifth of the cargo sent by air and two-thirds of the passengers. The 747 was the dominant civil transport in moving both passengers and cargo.

Civil-style, wide-body transports were more desirable than the C-141 for carrying bulk cargo because (1) they used civil airfields en route, thereby relieving the congestion at the main en route military airfields (Torrejon and Rhein-Main); (2) they delivered more tons per unit of ramp space at the destination airfield; (3) they delivered more tons per gallon of fuel required from theater fuel supplies; and (4) they used the more commonly available commercial fuel (Jet A), rather than the special fuel used by the Air Force (JP4). In contrast to

RAND MR406/1-03

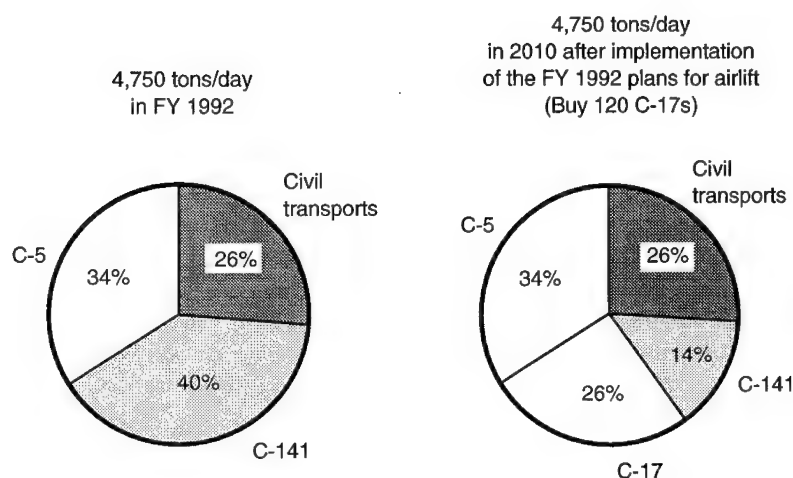


Figure 3—Estimated Capacity of the Total Airlift Fleet to Deliver Materiel to Southwest Asia After Stage II Activation of the FY 1992 CRAF

the high demand for civil-style transports, there were several signs suggesting that the supply of C-141 airlift capabilities exceeded the demands of the Gulf War airlift. For example, during the lull in Gulf War airlift activities (October and November of 1990), CRAF Stage I cargo remained activated even though the C-141's worldwide utilization rates fell to 3.4 hours per day⁸ (29 percent of our assessment of its capability assuming perfect scheduling).⁹ Finally, the civil-style transports had shorter loading and unloading times than the military transports, because the former were given priority over the latter. While the supply of civil-style cargo transports was insufficient to

⁸The C-5 utilization rate during this period was 4.2 (see Figure 4.6 in Chapter Four of Volume 2).

⁹Although the C-141 experienced a much higher aircraft availability than the C-5 (85 percent versus 68 percent) in the second surge of the Gulf War airlift (December and January), it had a lower percentage application of what our mission cycle analysis methodology assesses to have been its airlift capability (63 percent application versus 74 percent for the C-5) under assumptions of perfect scheduling. (See Chapter Four of Volume 2.)

meet the demands of the Gulf War's second surge for airlift, the supply of C-141 capability exceeded the demand.

The shift in demand from outsize to bulk cargo raises a serious question about the DoD's 1992 plans for altering the composition of the airlift fleet. As Figure 3 shows, those plans would have increased the amount of outsize capacity from about one-third to two-thirds of the total airlift capability for cargo, because the C-17 can carry most types of outsize materiel. Given the high cost of outsize capabilities and the modest demand for outsize airlift during the Gulf War (Figure 2), the DoD is faced with a major decision regarding the composition of the military airlift fleet. To contribute to that decisionmaking process, Chapter Six addresses the costs and benefits of alternative fleets for military airlift.

AGING AIRCRAFT

The C-141 fleet has been experiencing periods of partial capability as fatigue and other problems with aging systems have forced the Air Force to ground or restrict its operations. The Air Force has studied options for overhauling the fleet and replacing selected systems, such as the engines. The cost of such overhauls ranges from several billion dollars to over \$10 billion, depending upon the scope of the overhaul. Retirement of most or all of the C-141 fleet would provide an opportunity to procure new aircraft that could improve the DoD's ability to satisfy future needs for airlift at the least cost.

GETTING THE MOST FROM CIVIL AIRLIFT

In exchange for receiving international transportation business from the DoD, at prices established by the department, air carriers commit aircraft to the international segment of the CRAF. The amount of business a carrier receives is a function of the numbers and types of aircraft that it commits to each of CRAF's three stages of activation.¹ Although civil airlift provides the DoD with a very cost-effective source of augmentation for military airlift, the amount of civil airlift that the DoD can depend upon in the future is uncertain.

COST-EFFECTIVENESS FOR THE DoD

For a very small cost, the DoD has had on call a very substantial airlift capacity. Replacing the CRAF's 1992 Stage II capability with military-style transports would have cost the DoD about \$1 billion annually (1992 dollars) over the past several decades.²

While maintaining reserve airlift capacity in the civil airlift fleet is relatively inexpensive,³ the reverse is true for maintaining reserve capacity in the military airlift fleet. To have adequate capacity for major crises, the military airlift fleet has a total capacity several times

¹During 1992, a Stage III activation would call upon 400 aircraft to provide triple the capacity of a Stage II. Stage II would provide four times the passenger capacity of Stage I and double the cargo capacity of Stage I. See Chapter One of Volume 2.

²Replacing the Stage III capability would have cost about \$3 billion annually.

³"Reserve capacity" refers to capability that can be drawn from the civil sector and from increased use of active-duty units, the U.S. Air Force Reserve, and the Air National Guard.

the average daily use.⁴ Although the reserve capacity is often called upon to support responses to small crises, it is very rarely called upon at the level experienced during the Gulf War. The cost of acquiring equipment and maintaining crews must nonetheless be routinely incurred.

Although holding reserve capacity in the CRAF is far more cost effective than holding the reserve in the military airlift fleet, the government has a financial incentive to use its own resources (for which it has already committed funds) in a crisis to the extent that they are conveniently available, rather than give additional business to CRAF carriers.

DoD's UNCERTAIN ACCESS TO CIVIL AIRLIFT

To build a long-range airlift capability for a major reinforcement of NATO, the DoD enlisted 400 civil-style transports from civil air carriers to support the three stages of the CRAF. Even so, it still fell short of the 66 million ton-mile per day capability it had set as a goal in the Air Force's 1983 Airlift Master Plan for cargo. All but 23 of the 400 aircraft were enlisted in an "as is" condition. The 23 wide-body passenger transports (19 of which were Pan Am 747s) had their floors strengthened and doors enlarged to carry oversize cargo (e.g., trucks). In its 40-year history, the CRAF has been activated only once, for the Gulf War. Stage I activation of the passenger segment of CRAF provided the use of about one-twelfth of the CRAF's total passenger capacity (based upon a Stage III activation). Stage II activation of the cargo segment provided the use of about one-third of CRAF's total cargo capacity (based upon a Stage III activation).

Although civil airlift was a significant contributor during the Gulf War, concerns about the extent and frequency with which civil airlift can be called upon have arisen as a result of that experience. Whereas the small air carriers were eager for the Gulf War business, the larger passenger and cargo carriers were reluctant participants, because their withdrawal of equipment from commercial routes gave non-CRAF competitors an opportunity to gain long-term increases in

⁴Planning factors estimate capacity at five times daily use; we estimate about four times, assuming best use of resources.

their market shares.⁵ Thus, the large air carriers have learned that too frequent and too great a reliance on them could be very disruptive to their operations and could seriously risk loss of their market shares to less involved carriers.

Even before the Gulf War there were signs of weakness in the supply of CRAF aircraft. The participation of the large air carriers had fluctuated over the years, as had the total number of aircraft enlisted in the CRAF. The reality is that the structure of the CRAF and the defense business environment do not support sustaining a large CRAF. The profit potential for CRAF-related business is a small factor for large air carriers. Defense business, the sole enticement for joining the CRAF, is declining. Most of the advantages of CRAF are realized by small carriers, partly because the government's prices favor charter-style operations. Most of the large carriers have left the charter business, because they found that they cannot compete with the small carriers. Also, the civil air carriers have mostly been given passenger business; therefore, air freight carriers have had less opportunity to benefit.

Furthermore, a large part of the air carrier industry is becoming less "CRAF friendly" with the major changes affecting the U.S. international flag carriers that were a natural source of large transports (particularly the 747 family of aircraft) for the CRAF. Pan Am has gone out of business. TWA has reduced its international operations. Northwest has taken on a foreign partner to weather a financial crisis. The movement toward international business arrangements by several air carriers might limit their ability to support U.S. national interests in some situations. Moreover, financial problems are forcing air carriers to reevaluate risks and potential profits.

Finally, most of the large transports are being purchased by foreign air carriers, and U.S. air carriers are moving away from the 747-size aircraft toward smaller aircraft that offer greater scheduling flexibility in competing for business. For all of these reasons, CRAF's long-term ability to contribute as it did during the Gulf War is in doubt.

⁵Many competing carriers had not made large commitments. Some were foreign airlines, who cannot participate in the CRAF. Some lacked significant quantities of transports capable of international flights. Some had decided that the benefits of CRAF were outweighed by the risks.

IDEAS FOR IMPROVING CRAF

Because some large air carriers currently view the benefits from CRAF-related business as insufficient compensation for the risks of disruptions to business that occur during activation, we explored a broad range of ideas for improving incentives for carriers to participate, including the following:

Make Participation in CRAF Compulsory for All Carriers

At one extreme, a compulsory system could be considered wherein the government would draft needed resources and regulate markets to protect those air carriers that had the types of resources that the government called upon during the crisis. Although the government might establish a ready capability to regulate domestic markets, as it once did under regulation of the airline industry, that would only partially protect air carriers, because it would be extremely difficult to protect U.S. carriers on routes where they compete with foreign carriers.

Expand Business Offered in Exchange for CRAF Participation

Broadening the business base that might be made available to CRAF carriers is conceptually very attractive.

- **Shift DoD's international cargo to civil air carriers.** The DoD's international airlift needs, however, are already nearly fully committed to CRAF carriers for passengers. Providing more cargo business is a possibility. However, it comes at high cost in reduced opportunities for military transports to recover operating costs and, more importantly, in reduced opportunities to provide training. Moreover, shifting even most of the cargo to the CRAF carriers may not compensate for the decline in passenger business that will occur with the drawdown of U.S. forces stationed overseas.
- **Include additional government air travel within the CRAF program.** Another possibility is to bring other government business within the CRAF program. We failed to find, however, an easy way to accomplish this, because we foresaw serious conflicts with established objectives and policies of other government in-

terests, as well as probable resistance from the large air carriers. The major airlines, for example, could be expected to resist such a move unless they could be assured of a level playing field. However, we found no satisfactory way to level, both in fact and appearance, the playing field in such a diverse industry so that neither the substance nor the appearance of unfair advantage would occur during an emergency activation.⁶

Provide Direct Payments Annually for Enlisting in CRAF

Business considerations could be broadened in the form of annual payments in exchange for commitments to a modified CRAF.

- **Make payments to offset declines in defense business.** The government could make direct payments to CRAF carriers to ensure that CRAF business plus the direct payments covered the fixed costs of their 1989 CRAF-related operations.
- **Use sealed bids to set payment levels.** A different direct compensation approach might be implemented in the form of periodic sealed bids to government requests for commitment of particular services, such as 747 freighters or wide-body passenger transports. The carriers would bid on the amount of the annual payment they would require to commit aircraft to the CRAF.

This approach appears to have serious political drawbacks. First, it would appear to the public that the government was subsidizing the air carrier industry. Second, even within the industry, not all carriers would benefit. Because carriers lacking the kinds of equipment of interest to the government would be competing against those that did, it is reasonable to expect the non-benefiting carriers to argue against government support for their competition.⁷

⁶For example, many air carriers do not have any of the long-range international transports the DoD needs, but they compete with air carriers that are using such transports in markets where they are vying to maintain the loyalties of the same customers.

⁷Economists are divided on this subject. Some economists reject our arguments, because the government is involved in subsidies in many other areas. However, the matter of subsidies for the transportation sector has been the subject of significant public debate in the past. For example, when Pan Am sought government subsidies to offset

Provide an Activation Surcharge

To avoid the subsidy issue and to minimize the government's short-term expense, the carriers might be encouraged to take the substantial portion of their compensation in the form of a surcharge during periods of activation. The surcharge would provide the carriers compensation above and beyond the normal peacetime formula, which was also used during the Gulf War activation. Given the low likelihood of activation, especially as long as there is a significant military airlift fleet, using a high surcharge as an enticement may be in the government's best interest. For example, providing the air carriers during the Gulf War a 50-percent surcharge would have increased the expense of that airlift by about \$800 million. Maintaining comparable capabilities in the military airlift fleet (even using civil-style transports) would have cost about \$500 million annually. However, the public may view large surcharges as war profiteering and fundamentally objectionable.⁸

Adopt a Voluntary Program with No Precommitments

At another extreme of the spectrum of possibilities lies a voluntary system in which the government would pay whatever prices are necessary during a crisis to purchase the airlift services then needed. For example, during the Gulf War, two-thirds of the CRAF missions were flown by air carriers willing to provide more aircraft than their CRAF commitments required. Most aircraft committed by the large air carriers are in Stage III, which was not activated due to carrier resistance.

An advantage of a voluntary approach is that it allows all air carriers to respond in ways that are sensitive to the immediate state of the market rather than making long-term commitments. During a major crisis, such as the Gulf War, some carriers may experience a greater

subsidies that foreign air carriers were receiving from their governments, it failed to obtain necessary support. One of the issues that arose in that debate was whether the government should subsidize a company that some believed was in need of better management.

⁸Economists are divided on this point. Whereas some see this as a serious political liability, others believe that argument is bogus. Whether activation surcharges, large enough to make a difference, would be accepted by the public remains uncertain.

decline in business than others and may be more interested in offering capacity to the government that had become surplus. However, such a spot market makes planning difficult and raises issues about the dependability of the CRAF. Thus, improving the CRAF will be difficult, because, for each of the possibilities we explored, we found significant impediments to implementation.

LOWERING EXPECTATIONS FOR CRAF TO IMPROVE SUPPLY

As noted, large air carriers may choose not to participate in CRAF in the future if they judge that the likelihood of a large-scale activation is too high to justify the business risks. The DoD can do two things to lower the perception of such a likelihood: reduce air carrier exposure and/or reduce the likelihood of activation.

Reducing exposure may be a beneficial tactic, because Stage III had more than tripled the size of the air carrier commitments by relying mostly upon the large air carriers.⁹ Because the government found itself unable to activate Stage III for the Gulf War, the reality may be that a president would never activate Stage III because of the impact on the private sector unless it was the most serious of national calamities. In such a case, special authorization presumably would be forthcoming either from existing statutes or from a special act of Congress. Thus, it seems that continuing a high expectation for CRAF's three stages may actually be counterproductive to recruiting at least some participation by most large carriers and spreading the exposure to disruption of business. By spreading the burden, the DoD can reduce the likelihood of economic hardship that compels carriers to lobby against activation.

Reducing the likelihood of activation is another potentially beneficial tactic. The DoD could do this by ensuring that the military airlift fleet has the right mix of transports to avoid activation of the CRAF for most airlift emergencies. This means that the DoD would need to maintain a level and composition of airlift capabilities sufficient to make activation a rare event.

⁹Since the completion of this research, the DoD has increased the size of Stage II and thereby reduced the amount added by Stage III.

Regardless of the difficulties with its implementation, the CRAF program is a very cost-effective means of providing emergency airlift for those rare occasions needing very large amounts of airlift. As such, our recommendation for its preservation is to set realistic expectations for its size and to make sure that the military airlift fleet is large enough and versatile enough that the CRAF would rarely have to be activated.

GETTING MORE AIRLIFT FROM MILITARY TRANSPORTS

The military airlift used to support the Gulf War was only 40 percent of the capacity that the Air Force thought it had because of overly optimistic planning factors. Using more airfields and better command and control could raise C-5 utilization rates from 5.5 hours per day (Gulf War) to near 7.4 hours, which is a theoretical limit that assumes perfect scheduling. Adding aerial refueling could raise the theoretical limit by about 30 percent to almost 10 hours per day. Other military transports would experience similar improvement percentages.

USING MORE AIRFIELDS FOR AIRLIFT OPERATIONS

The utilization rates for military transports were low during the Gulf War airlift because (1) ground times for loading and unloading military transports and for refueling exceeded planning factors, (2) airfield capacity limitations slowed the airlift system, and (3) the need to repair broken aircraft limited the availability of military transports. To avoid airfield congestion that would have caused even lengthier ground times at aerial ports of embarkation (APOEs), the loading of transports was slowed from two to one aircraft per hour for both Army and Air Force units. Finally, the use of only one aerial port of debarkation (APOD) at Dhahran for most of the Army's units slowed the arrival of forces in-theater because of limitations of the facilities (fuel and ramp space) that were assigned to supporting the airlift at Dhahran. Later, additional airfield space and more refueling resources were allocated for airlift.

Bottlenecks at APOEs and APODs can be avoided by simultaneous deployment of multiple units from a set of CONUS APOEs to a set of theater APODs. Although such a pattern is common for the Air Force, it is not the Army's usual practice. During the Gulf War deployment, airlift resources first moved the 82nd Airborne Division and then joined sealift in deploying the 101st Air Assault Division. Such a sequential delivery of Army divisions and their supplies was constrained by the rate at which units could be loaded at the APOEs and received at the main APOD. By using multiple APOEs and APODs, the DoD could dramatically reduce congestion and improve efficiency of airlift.

Although operating more aerial ports increases the need for materiel-handling resources (both equipment and personnel), such costs are small in comparison to the costs of buying transports and maintaining the proficiency of their crews.

USING AERIAL REFUELING FOR MORE MISSIONS

Utilization rates during the Gulf War airlift were also held down by the frequent needs of military transports to land for refueling. In completing one round trip from a unit's APOE to its APOD and back to the same APOE, military transports had to make from three to five additional stops for fuel, fresh crews, or maintenance at a home base for that type of aircraft. Each stop introduces the opportunity for a part to fail or a delay to be caused by facility limitations, weather, or changing operational priorities. Aerial refueling, on the other hand, allows military transports to fly nonstop between APOEs and APODs, provided that (1) fresh crews are provided at the APOEs and the APODs, (2) the crews include additional personnel for long flights, and (3) there are no urgent maintenance needs that can only be satisfied at a home base. However, aerial refueling of transports was rare for the Gulf War airlift because too few pilots were qualified and flight crews were not provided facilities to rest at even the most frequently used APOD—Dhahran.

Benefits

Military transports could provide 30 percent more airlift with the aid of aerial refueling, according to our analysis. To assess how aerial

refueling might improve utilization of transport aircraft, new research tools were developed to explore a wide variety of candidate combinations of tankers (KC-135R and KC-10), transports (C-5, C-141, C-17, and a military version of the 747-400F), routes (polar and great circle), and methods for refueling missions (rendezvous, buddy, and rendezvous in vicinity of the tanker's deployed operating base).¹ For a deployment to Southwest Asia, the most effective combinations were to use KC-10s to rendezvous with C-5s or 747-400Fs (equipped with aerial refueling capability) and to use KC-135Rs to rendezvous with C-141s or C-17s. The most effective rendezvous locations were near tanker operating bases, with those bases being the same bases that the transports would have used if aerial refueling had not been part of the concept of operations. Although polar routes would be slightly less time consuming, such routes required more tankers and tanker crews.

In contrast to RAND's result, analyses by the AMC have shown a throughput improvement of only up to 6 percent, depending on the scenario. Much of the difference between the RAND and AMC estimates comes from two sources. First, contrary to current AMC practice, our analysis assumed that flight crews could be provided appropriate facilities for rest between missions at both APODs and APOEs to avoid additional stops to change crews. Second, our analysis assumed that the reduction in landings and takeoffs would reduce the need for maintenance and thereby reduce the number of stops required at a home base. Both RAND and AMC assumed that bases would be conveniently available to support tanker operations.

Although our analysis showed that deviations from these assumptions quickly erode the benefits of aerial refueling, the analysis also showed a significant benefit from minimizing the number of stops and keeping transport aircraft airborne for as long as possible. Thus, to derive the most benefit from aerial refueling, the Air Force may find it beneficial to consider new policies calling for (1) stopping at a home base only when needed for maintenance and (2) changing crews only when aircraft must land to load/unload or to receive essential maintenance.

¹See Chapters One and Four of Volume 2 for a description of the models that were developed.

Although the Gulf War's low utilization rates for the C-5 made it a strong candidate for aerial refueling, the C-17 and the C-141 would also benefit from aerial refueling because of their more limited range (Figure 4). Gulf War airlift missions typically required transports to fly between 3,300 and 3,700 n mi between opportunities to refuel. Scenarios requiring greater flight distances and westbound deployments that would encounter headwinds (to Korea, for example) would increase the value of aerial refueling, especially for the C-17 and C-141.²

A military version of the 747 received less benefit from aerial refueling, because it can fly farther between refuelings than the military transports and, because of its higher reliability, it is less likely to produce a system failure when it stops for fuel.

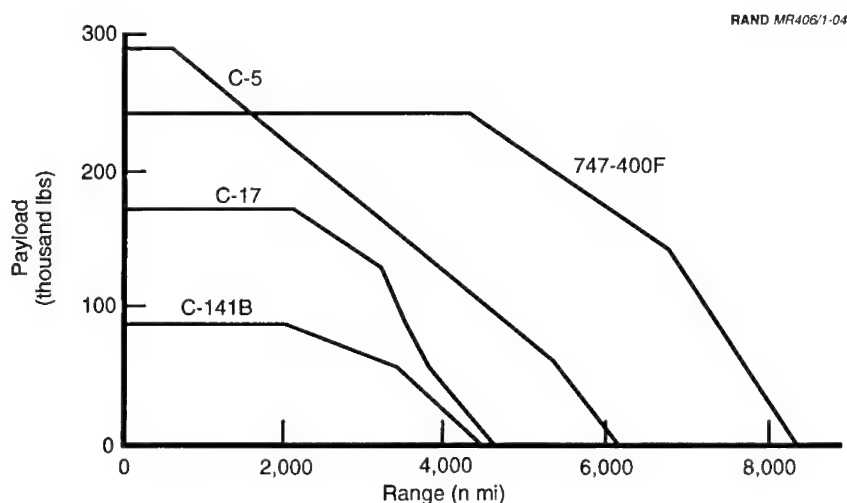


Figure 4—Payload as a Function of Range for Transport Aircraft

²A 70-kt headwind (not uncommon for westbound flights) can reduce a military transport's maximum range by 400 to 500 n mi for typical deployment loads.

Cost

Aerial refueling, however, is very costly. So costly, in fact, that it is less expensive to procure and operate additional transports than it is to pay the life-cycle expenses attributable to aerial refueling for the scenario we examine in Chapter Six. The added costs of aerial refueling include additional operating and support costs for the transports and the operating and support costs for the tankers,³ assuming that additional tankers do not need to be procured. If tankers have to be purchased, the costs of aerial refueling become even greater. The costs for the transports include additional operations to keep crews qualified for aerial refueling. More flight crews are also needed to provide the extra crew members required for long missions.

Even if the procurement costs of the tankers are not charged to airlift (if, for example, there were a surplus of tankers), the costs of aerial refueling are still high because of the combined costs of additional crews for the transports (needed for very long missions) and the operating and support costs for the tankers.

Planning and Employment of Tanker Forces

We found that dedicating tankers to the airlift mission is not justified on economic grounds for a deployment to Southwest Asia where we assume the availability of en route bases.

If, however, a transport like the C-17 were precluded from participating in an airlift because en route bases were too far apart and/or headwinds were too great, the high cost of aerial refueling would be justified by the benefit of allowing the C-17s or other range-limited aircraft to participate in the airlift. Thus, whether the DoD plans its tanker force to support airlift missions depends upon its assumptions about the possibility of someday lacking needed en route bases.

Finally, even if no tankers are dedicated to the airlift mission area, tankers assigned to other mission areas may be borrowed during

³Economists are divided on whether the tanker costs should be included, because tankers can be used for other purposes. See Topics 47 and 79 in Volume 3.

some phases of an airlift to deploy urgently needed materiel and personnel more quickly.

USING BETTER COMMAND AND CONTROL

The airlift job for a very large crisis can be thought of as a need to move a mix of cargo and personnel from one mix of bases to another mix of bases by using a mix of transports and any available tankers that might be borrowed to boost airlift capacity. The problem then becomes one of matching transports with loads, bases, and tankers. Some transports can take off from bases with short runways and land at bases with short runways. Other transports need bases with long runways. Such an approach to airlift, however, increases the pressure on command, control, and communication to match airlift and tanker resources (including infrastructure) with needs continuously. Upgrading command and control, as well as communication and computer systems, is crucial to getting the most from airlift and tanker resources.

Moreover, if the DoD increases its dependence upon civil-style transports, the value of better C⁴ will be even greater if it allows loads to be prepared to exploit the capabilities of particular types of transports. For example, the private sector routinely prepares pallets and loads containers tailored to provide maximum utilization of the available volume within the transport. For example, a 10- to 20-percent increase in payload can be achieved by knowing what type of transport will be carrying a particular load. The C⁴, therefore, has many ways to significantly leverage the DoD's investment in airlift.

The value of improved C⁴ must, of course, be weighed against the cost of achieving the improvements. It seems, however, that the ability to deliver more with a given set of airlift resources—and the cost of those resources—should justify a significant investment in improving C⁴.

An advantage of the military transport is its ability to access more airfields than its civil counterpart. Better exploitation of that advantage and earlier recognition of the ramp and fuel needs of the transports would have provided airlift an opportunity to move materiel and personnel more rapidly for the Gulf War, as theater commanders had desired on several occasions, such as in August and September

of 1990 and January 1991. Airfields, ramp space, fuel, and other infrastructure resources that can limit airlift performance must be managed effectively for airlift to satisfy future needs at the least cost.

**CONTINUE REPLACING THE C-130 WITH A MODERN
C-130 DESIGN**

Because the C-17 was conceived during the early 1980s as a transport that would have the austere airfield capabilities of the C-130, the Air Force's original plan was to use the C-17 to replace both the C-141 fleet and some of the C-130 fleet. Thus, at the time of this research, the Air Force inquired whether it could cut costs by stopping the C-130 production line now and relying upon the C-17 to provide necessary replacements for retiring C-130 transports. Because of the C-17's design changes, the Air Force asked RAND to examine whether the C-17 could be relied upon to carry out many missions now performed by the C-130.

Of the many factors that influence the suitability of an airfield for use by a transport aircraft, runway characteristics are often among the first to be considered. During 1988, the organization now known as the AMC examined the C-17's ability to access the world's airfields by analyzing the number of airfields in the Defense Mapping Agency's (DMA) worldwide database that had at least one paved runway.¹ Of those, AMC selected runways that were at least 90 ft wide and 3,000 ft long and that had been assessed by DMA as being suitable for use by aircraft with LCN ratings as high as 20. Our analysis of DMA's 1992 database for South America, Africa, and the Middle East shows that about 3,400 airfields satisfy these minimum requirements (Figure 5).²

¹The DMA database includes the world's airfields with the exceptions of the United States, China, and the former Soviet Union and its allies.

²Of the 4,619 airfields in Figure 5, 73 percent are paved.

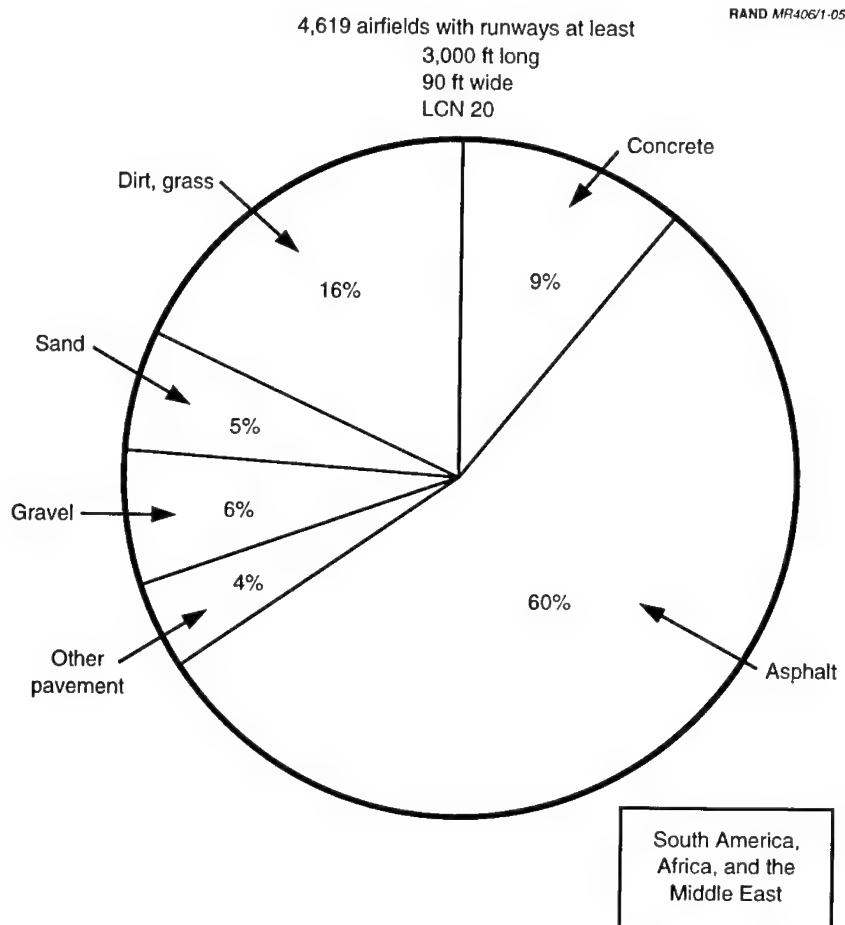


Figure 5—Airfields with a Runway Large Enough for the C-17 and with at Least an LCN 20 Rating from DMA

Of course, a runway suitable for use by aircraft with LCN ratings up to 20 will experience accelerated wear and eventual failure when used by an aircraft with an LCN rating of 48. Our research finds that an LCN 20 planning factor is unduly optimistic for all combinations of runways and aircraft that we have examined, with the exception of the C-27, discussed later in this chapter. As Chapter Five of Volume 2

illustrates, using such a low LCN masks important differences in the LCN characteristics (and comparative abilities to use airfields) of alternative transports, such as the C-130, C-17, and C-5 (discussed in Chapter Six).

In addition to being able to use these 3,400 airfields, the C-130 can also use another 1,200 airfields with unpaved runways that satisfy the AMC requirements (Figure 5). Because of its landing gear, the C-130 has more access to unpaved runways than does the C-17. The C-130's engines may also contribute to better access. The C-130's turboprop engines may be better suited for operations on unpaved surfaces than the C-17's turbofan engines, because the air entering the turboprop engine is moving at a much lower speed than the air entering a turbofan engine. The lower airspeed correlates with a lower threat of entraining foreign objects that can damage the engine. Such engine damage was illustrated by the C-5's unpaved runway tests, which resulted in the C-5 being restricted from operations on such runways. In contrast, the C-130 often operates on unpaved surfaces. This aspect needs further examination, however, because other factors, such as engine placement, also influence the propensity for damage from foreign objects. Because the C-17's engines are placed closer to its wings than the C-5's are, the C-17 may be less vulnerable to such damage than the C-5.

The C-130 can use even more airfields than the C-17, because the design of the C-130's landing gear gives the C-130 a lower LCN than the C-17. Given comparable runways and missions (distance, fuel availability at the destination, etc.), the LCN for the C-130 is about 40 percent lower than that for the C-17 when operating on weak runways.³ Thus, for example, if each were to use a runway that the DMA had rated for aircraft with LCNs up to 20, the C-130 could complete more missions than the C-17 before the runway would be damaged enough to require repairs. Even accounting for the fact that the C-17 could deliver larger loads, we found that the C-130 still has the advantage in total tonnage that could be delivered prior to runway failure because of its low-LCN design.⁴

³For strong concrete runways, the C-130's advantage drops to about 15 percent.

⁴See Chapter Five of Volume 2.

Because of its smaller size and relatively lower-LCN design, the C-130 has a further advantage of being able to land on improvised landing strips, such as open fields and roads that could not be used by the C-17. Its lower LCN also gives the C-130 advantages over the C-17 in using paved runways that may be low in strength or in poor condition.

Therefore, if the Air Force tried to cut costs by stopping the C-130 production line now and relying later upon the C-17 to provide necessary replacements for retiring C-130 transports, it would give up some of its current capability to access the airfields and other landing sites now used by the C-130.

The capability of the C-130 to land on roads played an important role in the execution of the left hook during the ground war phase of the Gulf War. This access might be beneficially increased by modernizing the aircraft. Even its current airfield access is not sufficient for some new needs of the DoD, as indicated by the experience of the U.S. Southern Command. To increase its access to airfields in Central and South America beyond the current capabilities of the C-130, the DoD has been procuring the smaller C-27 transport, which can use shorter and weaker runways than those required by the C-130.

To increase the C-130's access to airfields in Central and South America, we explored the possibility of updating the C-130 design to improve its runway performance with a new engine and to lower its LCN by redesigning its main landing gear. These measures may double the C-130's access to airfields in South America. The new engines would also increase the C-130's range, although the redesigned landing gear would reduce the amount of such gains in range.

REPLACING TWO-THIRDS OF THE RETIRING C-141s

The 1992 plan to retire two-thirds of the C-141s was an opportunity to consider acquiring a new transport that would move the Air Force toward the mix of military and civil airlift that most effectively balances costs and capabilities to meet future needs. Because the condition of the C-141 fleet requires action long before a new transport could be developed, tested, and produced, the Air Force's acquisition possibilities are limited to acquiring an already developed transport, such as the C-17, the C-5, or a civil-style transport. We examined each of these, as well as the possibility of assigning tankers to refuel military transports, to make up some of the capability lost in retiring C-141s.

Some air carriers may object that government operation of civil-style transports violates the national airlift policy developed during the 1950s. At that time, the Air Force agreed to stop flying civil-style transports on international flights with government employees as passengers in exchange for the commitment of the civil air carriers to help carry passengers and cargo during an airlift emergency. However, because the private sector cannot be expected to provide a core capability to handle life-threatening situations posed by war, the ability to order and control the operation of transports, even under hazardous conditions, remains a distinguishing feature of military airlift that justifies the Air Force's operation of a broad range of equipment, possibly including civil-style transports.

THE BASE CASE

To provide a basis for evaluating incremental costs and benefits attributable to alternative options, we defined a base case that included those aircraft that the Air Force had planned (as of 1992) to retain in the inventory past the year 2010. We then developed alternative options for adding to the base case fleet. From the 1992 military transport inventory, the base case includes:

- 126 C-5s (109 primary assigned aircraft [PAA]).¹
- 94 C-141s (80 PAA) that the Air Force was planning to retain past the year 2010.

Retaining about one-third of the C-141 fleet would maintain a very efficient means for the brigade air drop, because a C-141 can carry up to 150 paratroopers and often carries about 120. The C-17, on the other hand, can carry only 102, even though the C-17 is 50 percent heavier than the C-141. However, any retained C-141s would need a thorough and very substantial overhaul to rebuild worn elements of the structure and the aircraft's systems. It would cost from \$1 billion to \$3 billion (1992 dollars) to so extend the life of one-third of the current fleet. The base case also includes the activation of a CRAF capability equivalent to that used for the Gulf War:

- 28 747-200F freighter-equivalent aircraft (1991 Stage II)
- 18 747-200 passenger-equivalent aircraft (1991 Stage I).

The C-130 was not included in either the base case or the alternatives for enhancing the base case for three reasons. First, the objective for the research was to find the right mix of airlift resources to serve future needs for intertheater airlift. For intertheater airlift, the time required to move a large force is long in comparison to the time required to move forces by surface within a theater. Second, we found that the C-17 does not have the capabilities to perform the spectrum of C-130 missions. Third, there is adequate tactical airlift capability, because the current fleet of C-130s is of ample size and has enough remaining service life to satisfy tactical airlift needs as currently

¹PAA are the aircraft assigned to operational units.

articulated by the DoD. For these reasons we proceeded on the assumption that intertheater and intratheater airlift can be analyzed separately with the C-130 performing most intratheater airlift missions.

Finally, we assumed that current efforts to improve command, control, communication, and computer processes will significantly improve the DoD's capability in several important areas: (1) scheduling unit movements and opening a sufficient number of APOEs to avoid congestion-induced delays, (2) matching different types of aircraft to the characteristics of the loads to be delivered, and (3) informing units about the types of aircraft for which they should prepare their loads.

ALTERNATIVES FOR ENHANCING THE BASE CASE

The options for enhancing the base case focused on fleets with different mixes of capabilities to illustrate how changing the mix of capabilities might reduce costs. Each option is designed to introduce its capabilities as C-141s are retired according to the 1992 retirement plan. Each option was time phased to replace the oversize cargo capacity of the C-141s as they retired. Thus, each option was sized to provide the same amount of oversize cargo-carrying capability. As the calculations were refined, greater attention was given to bulk cargo. We found that some options ended up with more capability for that type of cargo, because the civil-style transports have greater load-carrying capability with bulk cargo than with oversize. We selected five options to represent a broad range of possibilities for the C-17's inventory. The first option assumes a full procurement of C-17 aircraft, as was the DoD's plan in FY 1992. Two other options cut the C-17 procurement in half, and two final options had no C-17s.

- **Option A: The Air Force's FY 1992 Plan to Buy 120 C-17s.** Option A was designed to represent the Air Force's FY 1992 plan, which included the replacement of all but 80 PAA C-141 transports with 120 C-17 transports (102 PAA).
- **Option B: A Split Buy of 60 C-17s and 60 C-5Cs.** To compensate for a smaller C-17 fleet, Option B was designed to increase the size of the C-5 fleet. This option reduces the C-17 procurement

to 60 airplanes (51 PAA) and adds a new procurement of 60 additional C-5s (51 PAA).²

- **Option C: A Split Buy of 60 C-17s and 28 747-400Fs.** Because the capability to move bulk cargo efficiently was a significant need during the Gulf War airlift and is likely to remain so for many future crises, Option C includes the acquisition of a militarized version of the 747-400F freighter. This option calls for 60 C-17s (51 PAA) and 28 747-400F transports (24 PAA).
- **Option D: Use KC-10s for Aerial Refueling of C-5s and Buy 28 747-400Fs.** Only Option D was designed to explore how tankers might be used to help adjust to the possibility of there being no (or very few) C-17s. The option would compensate for the lost outsize capability by dedicating the existing 59 KC-10 tankers (57 PAA) to exclusive aerial refueling of the existing C-5 fleet.³ The addition of aerial refueling increased the need for C-5 flying hours to keep enough flight crews qualified for aerial refueling. Because aerial refueling also increased the mission duration for the C-5, additional personnel had to be added to the flight crews. This caused the number of flight crews to increase from 3.0 to 5.4 per PAA.⁴ The additional flying hours and flight crews contributed to the cost of this option, as did the operations and support costs for the KC-10 fleet. In addition, Option D included the procurement of 28 747-400F transports (24 PAA).
- **Option E: Buy 42 747-400Fs.** Option E was designed to address the possibility that a civil-style transport might replace the planned C-17 fleet. The option has no C-17s but includes 42 747-400Fs (36 PAA).

²Assumed configuration and costs for the C-5s are similar to the C-5B. Acquisition costs have been adjusted to 1992 dollars and include an allowance for restarting the production line.

³If assignment of the KC-10 fleet to refueling of the C-5s would create a shortfall in tankers needed to support combat aircraft, additional KC-10s or their equivalent would have to be procured at an added expense of about \$8 billion (FY 1992 dollars).

⁴The increase in crews might be reduced by (1) relaxing the limitation on the maximum flying hours a crew member may accumulate during a 90-day period and (2) more tightly managing the positioning and assignment of flight crews. Such measures might reduce the cost of Option D by, at most, 5 percent.

We did not consider the KC-10 in a transport capacity. Although it can use its belly fuel tanks to help match the range performance of the 747, it cannot match the payload capability because its remaining cargo capability is smaller. Even accounting for the lower costs per aircraft of a KC-10 compared to the 747-400F, the economics favors the 747-400F, as is evidenced by its wide use on commercial routes where the demand justifies a large aircraft.⁵

Other aircraft options were considered and rejected, because they lacked the long range that an aircraft like the 747-400F derives naturally from its large size, lacked the potential to yield significant cost savings, or lacked the capability to move significant amounts of oversize and bulk cargo.⁶ The intermediate-size wide-body transports (KC-10, DC-10, L1011, and 767) were rejected because their smaller cabins (compared to the 747) limit their ability to carry many oversize loads that are now carried by the C-141 and could be carried by a 747-400F. The standard cargo doors on the 747-400F permit a significant amount of oversize equipment to be loaded. Past studies have shown that freighter-configured 747s (such as the 747-400F) can easily carry at least half of the oversize cargo. This amount can be increased with a wider door and a stronger floor. Moreover, the superior operating economics of the 747-400 family (both passenger and freighter configurations) are illustrated by the fact that many foreign airlines and two U.S. carriers (Northwest and United) continue to buy this aircraft to carry large loads over long distances. Although designed 25 years ago, production continues to be robust, with over 1,000 deliveries to date. The long production run and design improvements have helped lower costs and increase

⁵On the other hand, one might argue that, because the KC-10 can serve as either a tanker or as a transport, its costs should not be assigned only to the airlift mission. However, the demands for airlift and the demands for tankers are likely to be greatest during the same period. Because a KC-10 would be employed as either a tanker or a transport during such a period, we assumed that it would be appropriate to assign its full costs to the mission mode in which it would be used during the peak period.

⁶If the DoD makes only a small investment in civil-style transports, the current C-5 fleet may be sufficient for carrying outsize and oversize materiel for most potential future scenarios. In that case, the intermediate-size civil transports may be of interest because a larger quantity of aircraft could be procured. At some point, the operational flexibility of a larger fleet may be attractive relative to operating a smaller fleet of large aircraft.

performance, maintaining the economic competitiveness of this unique aircraft.

For the most effective military use, the 747-400F should be modified to include (1) a wide side door for loading most oversize cargo, (2) a strong floor, (3) emergency exit doors and removable seating pallets for rapid conversion to a passenger configuration, (4) aerial refueling (for increased flexibility), and (5) military radio and navigation equipment. To cover the costs of these modifications, we assumed an additional \$20 million for each aircraft. Such modified 747-400Fs are assumed throughout this analysis.

APPROACH TO EVALUATION OF THE OPTIONS

To analyze the comparative costs and benefits of options for changing the composition of the military airlift fleet, we developed a challenging scenario to test the options, and we used a broad analysis of many aspects of costs and benefits. Rather than use the Gulf War experience as the scenario for testing the options, we constructed a far more challenging deployment scenario in terms of the loads to be delivered. We assumed that the five divisions in Table 1 had to be deployed simultaneously and entirely by air. That is, rather than deploying the heavy divisions with the most outsize materiel by sea, as was done for the Gulf War, they would be deployed by air. The DoD's Mobility Requirements Study used a less stressful scenario by deploying the heavy divisions by sea.⁷

To compare the capabilities of alternative fleets, we developed a new methodology that addresses both the costs and the mission performance of the airlift system to assess the many dimensions of both costs and benefits.⁸

⁷In recent analyses, the DoD has sought to select airlift and prepositioning programs that complement one another to provide for military requirements at the least cost. DoD staff recently reported that their analyses to date have found that, if we preposition the right mix of equipment and supplies, the cargo to be moved early in a deployment is predominately oversize and outsize. Our analysis did not examine prepositioning.

⁸See Chapters One and Four of Volume 2 for a summary of the approach and the major assumptions.

Estimating Performance

The throughput results were obtained by analyzing the airlifting of the five U.S. Army divisions that make up its rapid deployment force (Table 1). For convenience, the results of the individual unit movements have been summarized in terms of tons per day of cargo moved.⁹ In addition to the sheer tonnage an airlift fleet can deliver, two additional dimensions of benefit are of interest: (1) Some military transports have the capability to deliver loads to airfields with short runways, and (2) some military transports can deliver outsize materiel. Thus, to evaluate the several dimensions of benefits, we used the following measures of average daily deliveries:

- Tonnage of materiel that could be delivered directly to airfields with short runways (between 3,000 and 5,000 ft long). We used 5,000 feet to distinguish the capabilities of the C-17 and the C-5; minimum length runways for these aircraft are 3,000 and 5,000 ft, respectively, for most meaningful loads.
- Tonnage of outsize materiel that could be delivered to the theater.
- Total tonnage of materiel that could be delivered to the theater.

To analyze the comparative capabilities of the transports to access airfields, we calculated the LCN value for each transport given: (1) its landing weight upon arrival in theater and (2) comparable assumptions about runway construction and the condition of the soil underlying the runway.¹⁰ For each transport, we used its LCN value

⁹Deploying all five divisions solely by air would require 139 days if Option A were added to the base case. It would require 136 days with Option B. For each of the remaining options, there is more throughput capacity and hence shorter closure times. Under Option C, closure requires 123 days; under Options D and E, it requires 127 and 126 days, respectively. The more interesting closure times would be for the delivery of the combat capability equivalent to about one-sixth of each division (half of a brigade), because such a capability could be delivered in about three weeks. The Army, however, is not organized and trained to field a composite force of five half-size brigades that are ready for combat. Consequently, there were no time-phased deployment requirements available for analyzing such a deployment.

¹⁰For example, because the C-5 has twice as many wheels as the C-17, lower tire pressure, more widely spaced wheels, and only 50 percent more weight, the LCN for the C-5 is 24 to 33 percent less than the LCN for the C-17. See Chapter Five of Volume 2.

to assess the number of airfields in the DMA database that had at least one runway with a DMA LCN rating at least that high.¹¹

Estimating Costs

We assessed the fiscal costs of acquiring, operating, and supporting the alternative fleets. We also assessed the infrastructure costs, because, during the Gulf War, we saw how airlift capacity can be limited by infrastructure burdens, such as ramp space, that must be set aside for transports, fuel that the transports consume, crew members that must be accommodated, servicing that each aircraft requires, and the additional servicing that civil transports require over that for military transports. These costs were evaluated using the following measures of average daily activity:

- Ramp space allocated to unloading and servicing transports upon their arrival in theater. This is a way to measure the ramp space aspect of the relative Maximum On Ground requirements for the base case and the options.
- Fuel consumed—round trip—by the transports and the tankers that supported the C-5s in Option D.
- Number of crew members arriving in theater that would need accommodations for crew changes to occur in theater.
- Number of civil transports arriving in theater that would need the additional support facilities peculiar to civil transports.
- Number of total transports (civil and military) arriving in theater that would need support.

¹¹As observed in Chapter Five, the AMC uses a different approach to assessing airfield access, because it intends to make runway repairs as necessary. Using that philosophy, it has judged that both the C-5 and the C-17 could operate on paved runways that the DMA has assessed to be suitable for aircraft with LCN ratings up to an LCN of 20. With the AMC approach, the C-17 could access about 4,000 airfields, the C-5 about 2,300. However, we remain unconvinced that dependable airlift operations could be sustained by either aircraft on runways with such a low LCN rating. See Chapter Five of Volume 2.

We also evaluated life-cycle costs for 25 years (FY 1993 through FY 2017). Costs were evaluated with no discount rate and with rates of 5 and 10 percent.

Because there are significant uncertainties about future cost growth for the acquisition of the C-17 (beyond the FY 1991 projections), the C-17 portion of the cost estimates for Options A, B, and C may be low by as much as 15 percent. Also, the actual operations and support costs may be above or below estimates, depending upon the C-17's actual outcomes for reliability and maintainability. Moreover, the crew ratio might be reduced from five to four crews if our assessment of utilization rates is correct.¹² The cost estimates for Options D and E are on firmer ground (errors probably less than 15 percent), because more relevant acquisition and operational experience underlies the estimates.¹³ We provided for five crews for each 747-400F. The acquisition portion of Option B pertaining to the C-5 is likewise on firmer ground, because the production line has already been restarted once and because the C-5B's operational experience underlies the estimate for the operations and support cost. On the other hand, the estimate for Option B may overstate the C-5's operations and support cost because a C-5C would presumably have better reliability and maintainability characteristics than are reflected in the C-5B fleet.

RESULTS

Table 2 summarizes the benefits and costs for the base-case fleet.¹⁴ Table 3 summarizes the incremental benefits and costs attributable to alternative ways of adding to that fleet.

¹²Although that would reduce the cost for Option A by about 10 percent, other aspects of our estimates for operating and support costs have proved to underestimate these costs by a comparable amount.

¹³There is an issue, however, about the number of 747-400F aircraft procured for backup purposes that could reduce costs by about 5 percent for Option E (see Appendix D in Volume 3).

¹⁴The 1992 present values for the 25-year costs in Table 3 for Options A through E are (in billions of 1992 dollars) as follows:

- For a 5 percent discount rate, 26, 29, 20, 21, and 9.
- For a 10 percent discount rate, 19, 21, 14, 13, and 6.

Table 2
Aircraft, Costs, and Benefits for the Base Case

Parameter	Base Case
Number of aircraft	
C-141	94
C-5 A/B	126
747 cargo CRAF	28
747 passenger CRAF	18
Benefits	
Throughput in thousand tons/day to Southwest Asia	
Deliverable to short runways (<5000 ft)	0
Deliverable as outsize	1.20
Total tonnage to theater	2.61
Costs	
Infrastructure costs, average daily	
Ramp space (thousand sq ft)	1,968
Fuel consumed (thousand tons)	18.4
Crew member arrivals in theater	274
Civil-style transports arriving in theater	15.9
Civil-style plus military transports arriving	54.4
Life-cycle cost (for 25 years ^a in billions of 1992 dollars)	48

^aFrom 1993–2017.

Throughput

Deliveries to Airfields with Short Runways. Table 3 suggests that there may be significant differences among the options in their abilities to sustain the delivery of typical deployment loads to airfields with short runways. We found, however, that the differences are actually fairly modest. Less than 10 percent of the airfields usable by the C-17 could not be used by the C-5 because the runways were too short or too narrow.¹⁵ Similarly, less than 10 percent of the C-5–usable airfields cannot be used by the C-17 because the runway is too weak. Thus, because the C-17 adds little to the base case’s access to

¹⁵With the AMC approach of using an LCN of 20 for both the C-5 and the C-17, we found that 43 percent of the airfields usable by the C-17 could not be used by the C-5 because the runway is too short or too narrow.

Table 3

Incremental Benefits and Incremental Costs Attributable to Each Option

Parameter	Options				
	A	B	C	D	E
Number of inventory aircraft					
Buy C-17	120	60	60	0	0
Buy C-5C	0	60	0	0	0
Buy 747-400F	0	0	28	28	42
Use KC-10 ^a	0	0	0	59	0
Benefits					
Added throughput in thousand tons/day to Southwest Asia					
Deliverable to short runways (<5,000 ft)	0.96	0.48	0.48	0	0
Deliverable as outsize	0.96	1.04	0.48	0.37	0
Total tonnage to theater	0.96	1.04	1.41	1.30	1.39
Costs					
Added infrastructure costs, average daily					
Ramp space (thousand sq ft)	370	637	521	625	506
Fuel consumed (thousand tons)	7.1	7.2	6.4	7.1	4.2
Crew member arrivals in theater	77	90	64	131	38
Civil-style transports arriving in theater	0	0	8.5	9	12.8
Civil-style plus military transports arriving	25.6	21.4	21.3	14	12.8
Life-cycle cost (for 25 years ^b in billions of 1992 dollars)	39	43	30	36	15

^aTo refuel C-5s.^bFor 1993–2017.

airfields, the military value of the first measure of throughput (to short runways) is fairly limited.

Deliveries of Outsize Cargo. For outsize deliveries, the base case already has a significant delivery capability. For example, even though Option E fails to add to that capability, our analysis of adding Option E to the base case shows that the five divisions complete their deployment in slightly less time with Option E than with any other option. To do this, the 747-400F fleet in Option E had to deliver 29 percent of the oversize and much of the bulk cargo in our analysis scenario. The CRAF cargo transports delivered only bulk cargo. Thus, because the outsize requirement was satisfied by all options in our analysis, and because we used a scenario with significantly more

outsize than is usually the case, the military value of the second measure of throughput (outsize deliveries) is also fairly limited.

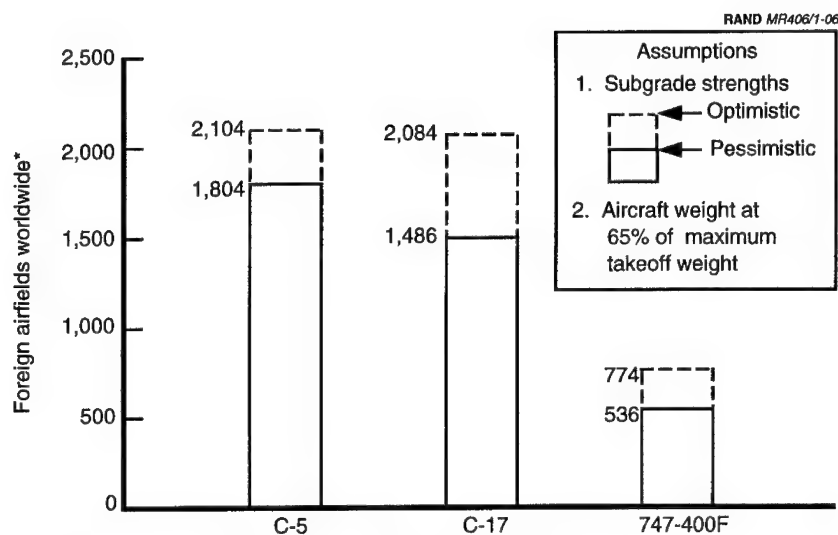
Total Tonnage to Theater. The total tonnage measure reflects the amount of outsize, oversize, and bulk that could be delivered. Because the pacing constraint on the airlift of materiel for the Gulf War was bulk cargo, the total daily tonnage that each of the five options can deliver to theater airfields is a measure of throughput with significant military value.

The total tonnage results in Table 2 are based upon the assumption that bulk cargo accounts for 60 percent of the cargo delivered by airlift, as was the case during the peak month of the Gulf War airlift. Because the 747-400F can carry a significant amount of oversize materiel,¹⁶ the options that include the 747-400F can maintain significant delivery levels even when bulk cargo needs are a lower portion of total cargo needs. For example, Option E matches the deliveries of Option A even if bulk cargo is only 38 percent of the total. During the first 30 days of the Gulf War airlift, it was 48 percent.

Figure 6 shows, however, that because of its runway limitations (length, width, and strength), a 747-400F can deliver to only one-third the number of airfields that could be used by the C-5 and the C-17.¹⁷ However, regardless of which option might be selected, the Air Force still requires at least one airfield to accommodate the CRAF transports in the base case. The base case requires 15.9 daily arrivals in theater by the CRAF 747-200 passenger transports and the CRAF 747-200F cargo transports. Furthermore, given the existence of at least 536 airfields around the world that can accommodate the 747, there is unlikely to be a major regional contingency or crisis where

¹⁶Depending upon the extent to which its floor is strengthened and its aft door is widened, the 747-400F can carry at least three-fourths of the oversize materiel (see Appendix B in Volume 3). In theory, CRAF transports can also carry oversize cargo; however, varying floor strengths made that problematic during the Gulf War airlift. Consequently, CRAF was used only to carry bulk cargo.

¹⁷Figure 6 also shows that we have estimated that the C-5 and C-17 have comparable abilities to use the world's airfields for major APOD operations in support of inter-theater airlift. This matter is addressed in Chapter Five of Volume 2 and Appendix C of Volume 3. Using different analytical methods, the Air Force estimates that the C-17 can access several times as many airfields as the C-5. Appendix G to Volume 3 identifies tests that could be pursued to address this issue.



*Except China and the former Soviet Union and its allies.

Figure 6—Airfields That May Be Used Without Exceeding Normal Stresses on Runways

the 747-400F could not make deliveries to the general region of interest.

To the base case capability of 2,610 tons delivered daily, Option A and Option B add about 1,000 tons per day from the locations in the United States of the Army's five rapid-deployment force divisions to bases in Saudi Arabia. For these same units, Option C, D, or E would add 1,300 to 1,400 tons per day to the base case.

Costs

Infrastructure Costs. Ramp space for Option E is comparable to Option A after adjusting for the fact that Option E delivers 45 percent more cargo. Option E requires 364,000 sq ft of ramp space in theater per thousand tons delivered daily compared to 385,000 sq ft for Option A. Option E has a clear advantage, however, in only requiring 3,000 tons of fuel daily to deliver 1,000 tons of cargo versus the 7,400

tons of fuel needed for Option A. Significantly fewer crew members need accommodations for Option E than the other options. And fewer total transports arrive in theater for Option E than Options A, B and C. The only cost measure in which Option E is at disadvantage is the number of civil-style transports arriving in theater. Option E produces 12.8 additional arrivals. If the Option E fleet were reduced in size to deliver the same amount of cargo as the Option A fleet, the number of additional arrivals would decline from 12.8 to 8.8. This is only about a 50-percent increase in the base case arrivals for the CRAF's civil-style transports.

Life-Cycle Costs. Option E, at \$15 billion, is nearly one-third the cost of Option B or Option A. The cost difference is so great because a single 747-400F costs less to procure than a single C-17, even though the 747-400F carries much more payload (see Figure 4), flies farther, and flies faster.¹⁸ Assuming that the C-5s and C-141s could carry the outsize and oversize cargo, a fleet of 42 747-400Fs can deliver 45 percent more cargo than a fleet of 120 C-17s.¹⁹

Option B, with a 25-year life-cycle cost of \$43 billion (1992 dollars), is the most costly. Next is Option A, with a 25-year life-cycle cost of \$39 billion (cost remaining as of FY 1993).²⁰ Option D proved to be surprisingly costly given the facts that no military-style transports are procured under that option and that the cost of buying tankers was also excluded. Aerial refueling, as was discussed in Chapter Four, is costly.

Considering all five dimensions of cost, Option E is the least costly in three dimensions and is tied with Option A in one dimension (ramp

¹⁸Because of its higher cruise speed and longer range between refuelings, the 747-400F had an average block speed of 462 kts in contrast to the C-17's 409 kts.

¹⁹The range capability of a large civil-style transport is superior for several reasons: (1) It does not bear the weight penalties associated with self-contained ramps and strong floors to withstand the concentrated loads of very heavy tracked vehicles (such as tanks); (2) it does not require a ramp and doors that open in-flight for air drop, allowing its aft fuselage to be better tapered to minimize drag; and, (3) unlike the single large cargo cabin in the military-style transports, the civil-style transports have a main deck and a belly compartment that allow for full use of the fuselage's volume when carrying either passengers or cargo.

²⁰Given the potential errors in the estimates of costs, the 10 percent difference in costs for Options A and B is probably not significant.

space).²¹ Options A and B are the least costly for one dimension (civil-style transport arrivals). Given the enormous difference in life-cycle costs, we find that Option E is the most attractive.

To illustrate this point, Figure 7 shows the life-cycle cost per standard unit of capability, where we define 1,000 tons delivered daily as one standard unit. It illustrates a nearly 4-to-1 cost effectiveness advantage for Option E (747-400F) over Option A (C-17). By viewing the results in Table 3 in terms of such a cost-benefit ratio we have adjusted for the fact that Option E delivers more capability (1,390 versus 960 tons per day) than Option A.

Discounting costs at a rate of 5 percent increases the nearly four-to-one advantage of Option E (Figure 7) to a 4.2 advantage. At a 10-percent discount rate, the advantage becomes 4.5 to one in favor of Option E.

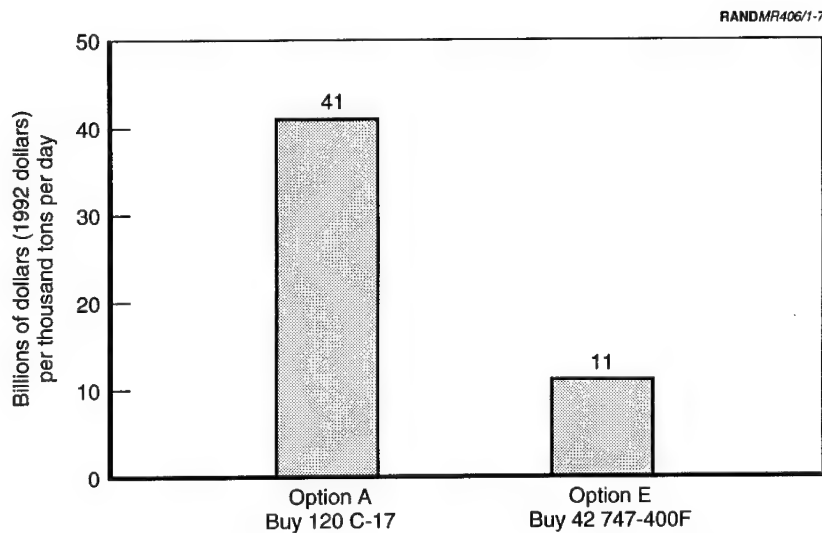


Figure 7—Life-Cycle Cost (1993–2017) per Standard Unit of Capacity to Airlift Cargo to Southwest Asia

²¹Ramp space is comparable in terms of daily tons delivered per unit of ramp space used daily.

WHAT IF?

Although a Southwest Asia scenario was used for the research, similar results would emerge for large-scale airlift support of major regional contingencies in other parts of the world provided that conveniently located en route bases are available for refueling and airfields are available in theater to handle the civil-style transports.

Assume that the Air Force pursues Option A. What if someday it confronts a scenario in which large amounts of bulk cargo need to be shipped rapidly by air? The main recourse would be to activate the CRAF and risk the possibility of undermining future commitments by large air carriers. On the other hand, suppose that someday the Air Force faces a scenario where long flight distances and or headwinds would force a reduction in C-17 payloads. The main recourse would be to divert tankers from other commitments to provide aerial refueling for the C-17s or activate the CRAF.

Now consider the alternative course of pursuing Option E. What if someday the Air Force has a situation in which access to 747-suitable airfields is denied in the area of interest? The main recourse would be to fly the 747-400F as far as airfield access would permit and then transfer its loads to military transports for completion of the mission. Or suppose that the Air Force someday confronts a scenario in which large amounts of outsize cargo need to be shipped by air. The main recourse would be to divert tankers from other commitments to refuel the C-5s. Of course, that would not be a problem if there were more tankers available than needed at the time.

Either Option A or Option E leaves the Air Force with significant means for managing its response to uncertainties. Option E's overriding advantage is low cost. The differences in capability and cost illustrated by Options A and E bring into sharp focus the fundamentally different missions for which military and civil-style transports are optimized. Although the military transports, and especially the C-17, are designed for a large spectrum of military purposes, such flexibility comes at a high cost. The issue is whether the entire military airlift fleet should have substantial flexibility or whether a segment of the fleet should be tailored to provide low-cost delivery of some of the needed cargo. The latter approach offers the promise of a larger overall capacity for airlift given a constrained budget. The

challenge for decisionmakers is to select the mix of these diverse resources that provides sufficient airlift capability for future needs at the least cost.

Finally, what if the government pursues Option E and then air carriers object to the government operating civil-style transports that may even carry some government employees during peacetime? The government could offer industry a government-owned, contractor-operated arrangement in which air carriers would use some of the equipment during peacetime and provide the government both the aircraft and the flight crews during an emergency. Such an outcome, of course, would reduce the cost of Option E.

MAIN CONCERNS RAISED BY THIS RESEARCH

As a method for maintaining capacity and reducing costs in the strategic airlift mission area, Option E has raised a number of concerns. Most of these are discussed in Volume 3. We address three of the most important concerns here.

Assessing the Magnitude of Potential Reductions in Costs

The magnitude of potential cost reductions attributable to substituting 747s for C-17s is a matter of debate because of differences in analytic methods. To illustrate the nature and the extent of the debate, we focus on differences between our 1992 research and the DoD's 1993 C-17 Cost and Operational Effectiveness Assessment (COEA). Most of the cost difference is the result of different estimates of how many 747-400Fs would be required. The difference in fleet size estimates is due mainly to different estimates for three parameters: (1) utilization rates, (2) payload, and (3) load mix. Figure 8 illustrates the effects of those differences on costs.

As already discussed, and over the 25-year period (1993 through 2017), we found that buying and operating a fleet of 42 747-400F transports instead of continuing the acquisition of 120 C-17s past fiscal year 1992, could result in savings of \$25 billion (1992 dollars).²²

²²Production of the C-17 did continue past 1992, and, thus, the current potential savings are less. As of late 1994, the potential savings are about \$20 billion in 1994 dollars.

The parameter values from the COEA analysis, on the other hand, suggest a much smaller potential savings. If block speed differences are not considered, the savings could be as small as \$5 billion (Figure 8). Even if they are considered, the savings based on COEA parameter values would still be as low as \$6 to 8 billion, depending upon how block speed differences are analyzed. See Appendix E of Volume 3 for further discussion of the differences in parameter values.

Loss of Flexibility: An Operational Concern

The present strategic airlift system is already fairly flexible and is complemented by a tactical airlift system of significant size and capacity. However, retirement of the entire C-141 fleet will reduce the DoD's strategic airlift capacity by almost half. The need to replace C-141s raises important trade-offs among costs, total capacity, and flexibility. If the cost of equal or greater flexibility means less capacity in the end, is that the right choice? If, on the

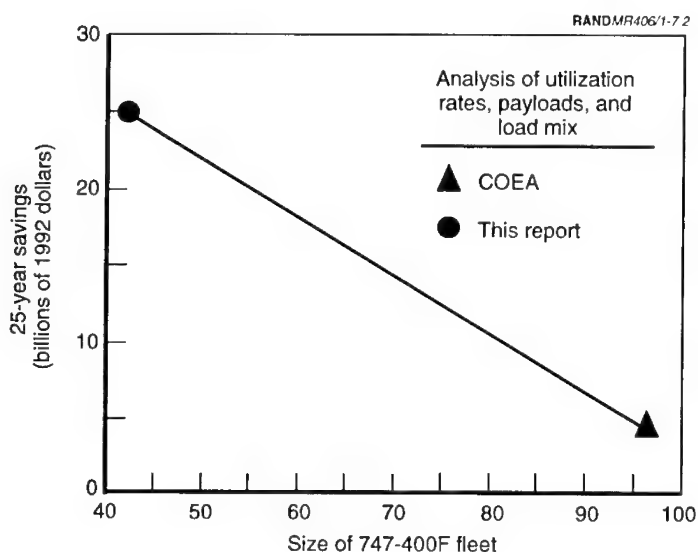


Figure 8—The 25-Year Savings Attributable to Substituting a 747-400F Fleet for 120 C-17s Is Sensitive to Estimates of Utilization Rates, Payloads, and Load Mix

other hand, we must trade current levels of flexibility to maintain current capacity, is the residual flexibility sufficient to satisfy future needs?

An important effect of implementing the recommended cost-saving strategy would be a decrease in the operational flexibility that only the military-style transport can provide. As discussed in Chapter One, this flexibility includes (1) the ability to use airfields with no preexisting infrastructure, (2) the ability to carry large items of equipment, (3) ease of loading vehicles, (4) the ability to airdrop personnel and materiel, (5) the ability to minimize exposure to threats through low-level flight and through rapid offloads on runways, and (6) aircraft system designs that are damage tolerant. The DoD would also forgo capabilities unique to the C-17, such as the ability to (1) use short runways, (2) deliver outsize materiel to short runways, (3) park in small areas, (4) maneuver in close quarters, and (5) back up on inclined surfaces. Unlike the 747, the C-17 can move all classes of cargo and deliver loads directly to austere airfields.

Retirement of the Entire C-141 Fleet Changes the Decision Context

Since completion of the research in 1992, the DoD has decided to retire the entire C-141 fleet by the year 2005. This action has created a new airlift investment decision that is different from the one we examined. The capabilities lost by the retirement of the last third of the C-141 fleet will need to be replaced by either the C-17²³ or some other military-style transport(s), such as the C-5 or possibly the C-130, although the C-130 flies slower and not as far as the C-17. The number and type of aircraft needed to replace the final third of the C-141 fleet, and therefore the cost estimate for the investment, will depend upon the key parameters at the heart of all airlift analyses: estimates for payloads, utilization rates, block speeds, load mixes, and level of CRAF participation.²⁴ Thus, our analyses of the right mix of military and civil airlift given 1992 conditions can be improved in

²³The number of C-17s required to replace the entire C-141 fleet is sensitive to estimates for payloads, utilization rates, block speeds, and load mix. See Appendix F of Volume 3.

²⁴See Appendix F of Volume 3.

two ways: (1) by examining alternatives for replacing the needed capabilities lost with the planned retirement of the entire C-141 fleet and (2) by analyzing and clarifying the uncertainties in the key parameters.

CONCLUSIONS

Finding the right mix of military and civil airlift is an extremely complex and demanding task, because it involves difficult trade-offs among operational and cost considerations at a time when there is uncertainty about both the future uses of airlift and the funds that will be available to acquire, operate, and support airlift capabilities. Moreover, there are significant differences in the costs and capabilities of different fleet mixes, and the DoD must justify what it selects as the right mix at a time when there is extraordinary competition for resources.

Our research, conducted against the backdrop of conditions in 1992, responded to Air Force interest in exploring the cost-savings potential—and the wartime implications—of increasing the DoD's reliance on civil airlift. Although the military-style transports—and the military's operation of those transports—provide essential operational capabilities, fiscal constraints and the needs for additional airlift capacity have always forced the DoD to turn to other, lower-cost means of airlift for delivering some of the passengers and cargo. The greater efficiency of the civil-style transports in delivering some types of loads and the cost-effectiveness of the CRAF arrangements have provided that lower-cost means to augment military airlift capabilities.

To provide the Air Force with our best independent estimate of the right mix, our research has sought to balance the competing needs for resources that are created by two important attributes of the airlift fleet:

- Capacity to respond to major needs
- Flexibility to adapt to a wide variety of airlift circumstances.

Investing too heavily in capacity at the expense of flexibility can produce a large fleet with inadequate flexibility for important jobs. On the other hand, investing too heavily in flexibility can produce a very versatile fleet that is too small and without sufficient capacity for very large airlifts.

To find the right balance of capacity and flexibility, we made independent assessments for the key factors that influence the costs and capabilities of alternative fleets: (1) the airlift jobs for which the Air Force needs to be prepared, (2) the extent to which the Air Force can prudently depend upon the CRAF being made available to augment military airlift, (3) the abilities of alternative transports to use the world's airfields for major APOD operations, and (4) the average values that would be realized for aircraft payloads, utilization rates, and block speeds when the airlift fleet (including CRAF) is used to conduct airlift operations for a specific scenario.

To maintain necessary capacity, we see a need for some shift in the mix toward the civil-style transport. To maintain necessary flexibility, we see a need to limit the amount of that shift and, at least initially, a need for the Air Force to be the operator of any civil-style transports that might replace retiring C-141s. At some future point, as CRAF arrangements continue to evolve and as the civil air-freight market continues to grow, it may be appropriate for such transports to be added to the CRAF to further reduce costs.

In 1992, we found that replacing up to two-thirds of the C-141 fleet with civil-style transports had significant merit on cost and capacity grounds, although it would reduce flexibility. Following an extensive documentation and review process, we believe that is still the case in late 1994.

In 1993, however, the warfighting CINCs decided that any such a reduction in flexibility would give up too much capability. Moreover, research conducted during 1993 had shown that our estimates for the size of the shift and the amount of the cost savings are sensitive to a few key parameters, for which wide differences in assessed values were emerging from different analyses. Estimates for these pa-

rameters (payloads, utilization rates, block speeds, load mix, and CRAF's availability) depend upon airlift scenarios, analytical methods, and assumptions used to evaluate airlift fleet performance. Thorough examination of the basis for such estimates is fundamental to understanding the reasons for differences in results. It is also fundamental to improving the analytical foundation for future decisions about the airlift fleet. To facilitate such examination, Volumes 2 and 3 describe the analytical basis for our estimates. Appendix G of Volume 3 also suggests some initiatives that would help the DoD reduce the disparity of approaches to this kind of analysis.

Another important dimension of the right mix is using the mix to its full potential. Here the DoD seems to have important opportunities to leverage its investment in airlift capabilities by improvements in C⁴ processes. Such improvements could facilitate improvements in other areas, including (1) making the best use of potential APOEs and APODs, (2) making the best use of aerial refueling, and (3) executing airlift operations to apply the capabilities of different types of transports more fully. These initiatives should also be considered as the DoD tries to balance the need for both airlift capacity and flexibility at a time when both the future uses of airlift and its future funding are uncertain.